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A Study of the Hydrologic Regime of the Battle River Basin

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A STUDY OF THE HYDROLOGIC REGIME OF THE BATTLE RIVER BASIN

by

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ABSTRACT

Streamflow records exist for the Battle River near Ponoka, Alberta, from 1913 to 1931 and from 1966 to the present. Analysis of these two periods has indicated that streamflow in the month of April has remained constant while mean flows in the other months have significantly decreased in the more recent period. In contrast, streamflow in the same periods at Battleford, Saskatchewan, has tended to increase. This indicates that the regime of the Battle River above Ponoka has changed.

From the analysis of monthly and daily precipitation recorded at Lacombe and Wetaskiwin, Alberta, it was concluded that April, May, and September flows for the Battle River near Ponoka are probably responding to precipitation characteristics. No clear relationship between precipitation and runoff is indicated for June, July, and August.

From Alberta census data, it has been demonstrated that the amount of deforestation in the basin upstream from Ponoka has probably had no significant effect on runoff. It has been postulated that a decrease in summer runoff may be related to higher growing season temperatures and the replacement of natural pasture by improved pasture and field crops. This decrease may be related to higher transpiration rates, increased infiltration potential, and increased soil moisture evaporation.

Many of the lakes in central Alberta appear to be responding to regional effects of climate and land use. Although poor correlations exist between lake levels and Battle River flows, significant correlations in mean annual lake levels occur between Gull Lake and Buffalo, Sylvan, Pigeon, and Wabamun lakes in the 1956 to 1966 period, and between Gull Lake and Sylvan Lake only in the 1967 to 1978 period. It has been postulated that the land use changes influencing streamflow also are affecting lake levels. Variations in elevation for Gull Lake (and possibly many of the other lakes in the region) do not appear to be related to artificial drainage, erosion of an outlet channel, buried valleys, bedrock fractures, or seismic exploration.

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1. INTRODUCTION

1.1 PROBLEM STATEMENT

Water resources planning within the Battle River Basin in central Alberta requires hydrologic information as to the availability and time distribution of water within the basin. The future development of industry and demands of water-based recreation activities require analysis of a large and reliable set of continuous streamflow data. However, such long continuous records are usually non-existent for prairie streams and the Battle River is no exception.

The Battle River near Ponoka, Alberta, has been monitored from 1913 to 1931 and from 1966 to the present, while at Battleford, Saskatchewan, useful records exist from 1913 to 1932 and from 1967 to the present. In order to fully utilize these records for planning purposes and possible flow reconstruction, it is necessary that these records be tested for homogeneity. Any inconsistences in the existing records should be identified and where possible the reasons for the inhomogeneity should be postulated.

Secondly, many of the lakes in central Alberta have developed into prime recreational areas but declining and variable lake levels have become of considerable concern, especially in the last few years. Several reasons have been suggested for these changes in lake levels but none has proved entirely satisfactory. Therefore, the second phase of this research project examines selected lakes in central Alberta and attempts to determine the parameters that control or influence lake levels.

1.2 STUDY OBJECTIVES

The specific objectives of this thesis can be summarized as follows:

1. To collect hydrologic records for the Battle River Basin;
2. Determine whether the Battle River has undergone regime changes between the earlier part of this century and the present;
3. Determine the probable causes for regime changes, if such changes have occurred, including the effects of climate, deforestation, and land use pattern changes;
4. Examine possible methods for extension of the period of record and the reconstruction of flows for the Battle River near Ponoka, if no regime change has occurred; and
5. Write a formal report.

In addition to the above terms of reference, it is proposed to determine whether the apparent fluctuations in lake levels at the selected lakes in central Alberta are regional in character or whether they are responding to highly localized influences. Recommendations concerning the approach to be taken in utilizing existing streamflow records for planning purposes will also be suggested.

1.3 STUDY AREA DESCRIPTION

The Battle River Basin is located in east-central Alberta and bounded by the North Saskatchewan River system on the north and the Red Deer River Basin to the south (Figure 1). The Battle River has its

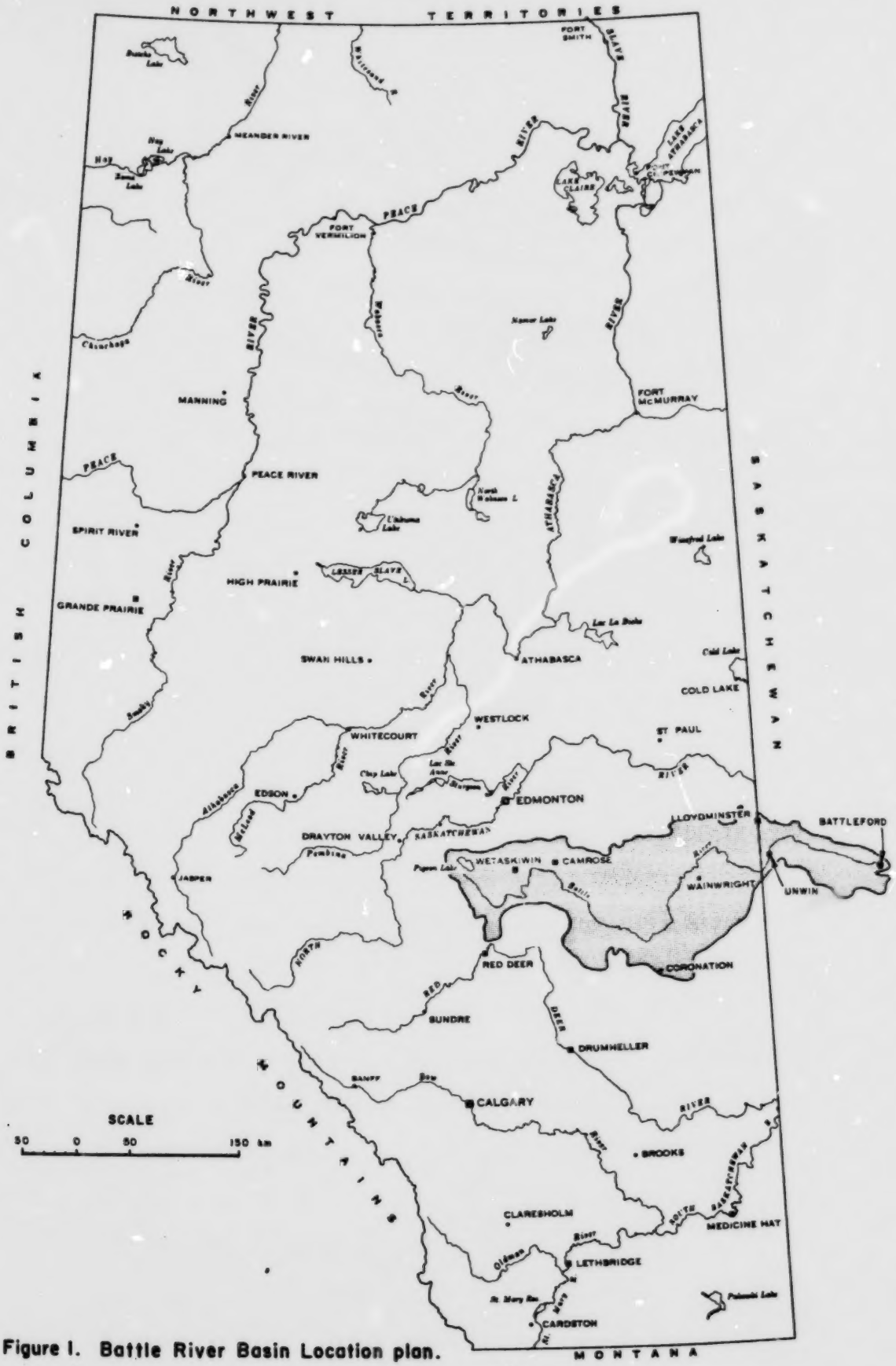

Figure 1. Battle River Basin Location plan.

source at Battle Lake, situated 73 km southwest of Edmonton, and flows in an easterly direction for approximately 480 km to the Saskatchewan border where it joins the North Saskatchewan River near Battleford, Saskatchewan. At the confluence, the basin drains an area of approximately 30 000 km^2, of which 25 000 km^2 are within Alberta.

The headwaters of the Battle River are characterized by rolling topograpphy with land rising to over 990 m above mean sea level. As a meandering stream within a shallow valley, the Battle River trends southeastward to Ponoka and then flows northeastward into the low, flat area near Samson Lake. Downstream of Samson Lake, the river flows in a northerly direction within a gradually deepening valley until it approaches Pipestone Creek. From here, the trend is southeasterly for 120 km and then northeasterly for approximately 100 km. Finally, the river flows in an easterly direction through eastern Alberta until its confluence with the North Saskatchewan River.

That portion of the Battle River Basin upstream from Alliance is characterized by a well-developed drainage network where runoff has direct access to channels. Below Alliance, the drainage pattern is characterized by numerous sloughs.

Mean annual evaporation for the basin varies from approximately 635 mm in the west to 800 mm in the southeastern regions, while mean annual precipitation varies from 500 mm in the west to 350 mm in the east (Figliuzzi 1978).

1.4 BASIN WATER USE

Water supply within the basin is partially controlled by the Coal Lake, Driedmeat Lake, and Forestburg reservoirs. The major industrial users of water within the basin include the thermal plant near Forestburg and the natural gas processing industry (see Table 1). The only industrial water user above Ponoka is the natural gas processing plant northeast of Pigeon Lake. Water withdrawals by industries such as the food and beverage industry at Wetaskiwin, Camrose, and Stettler, the non-metallic products industry at Camrose and Wetaskiwin, the primary metal products industry at Camrose, and the chemical products industry near the southeast boundary of the Battle River Basin are insignificant. However, Pierson (1976:6) reports that, "Although the amount of consumption by the (Forestburg) power plant is insignificant . . . an additional (1.5 million cubic metres) per year is lost through evaporation after water is discharged to cooling ponds".

From Table 2, it can be seen that industrial withdrawals have remained fairly constant during the 1968 to 1972 period.

The population of the Battle River Basin in 1976 was approximately 82 500, of which 32 000 reside in Camrose, Wetaskiwin, Ponoka, Stettler, Wainwright, and Lacombe (Pierson 1976). Municipal water supply is primarily from groundwater sources with an estimated 1975 contribution from groundwater being 77% and 23% from surface sources (Pierson 1976). However, actual consumption of municipal water is insignificant as it is assumed that 80% of the total withdrawal is returned to the basin.

Table 1. Industrial water use in the Battle River Basin, 1972 (after Pierson 1976).

Industry	Source of Supply	Annual Withdrawals		Annual Discharge		Annual Consumption		Consumption as % of Total
		$10^3 m^3$	$10^{-3} m^3/s$	$10^3 m^3$	$10^{-3} m^3/s$	$10^3 m^3$	$10^{-3} m^3/s$	
Natural Gas	Surface	243	7.7	82	2.6	161	5.1	
	Ground	1 177	37.3	492	15.6	685	21.7	89
Food & Beverage	Municipal	76	2.4	58	1.8	18	0.6	2
Primary Metal	Municipal	26	0.8	26	0.8	-	-	
Non Metallic Products	Municipal	8	0.3	2	0.1	6	0.2	1
Chemical & Chemical Products	Ground	5	0.1	5	0.1	-	-	
Sub Total		1 535	48.6	665	21.0	870	27.6	92
Thermal Power Plant	Surface	206 397	6 545	206 318	6 542	79	3.0	8
Total		207 932	6 594	206 983	6 563	949	30.6	100%

Table 2. Industrial water withdrawals from all sources (excluding thermal power) within the Battle River Basin (after Pierson 1976).

Year	Annual Withdrawals		Annual Discharge		Annual Consumption		Mean Monthly Consumption
	$10^3 m^3$	$10^{-3} m^3/s$	$10^3 m^3$	$10^{-3} m^3/s$	$10^3 m^3$	$10^{-3} m^3/s$	$10^3 m^3$
1968	1487.7	47.2	623.2	19.8	864.5	27.4	72.3
1969	1496.	47.5	638.2	20.2	858.2	27.3	71.4
1970	1491.8	47.3	635.9	20.2	855.9	27.1	71.4
1971	1487.3	47.2	631.8	20.0	855.5	27.2	71.4
1972	1535.0	48.7	664.5	21.1	870.5	27.6	72.7

Agricultural water uses within the Battle River Basin are for irrigation and livestock purposes. Irrigation licenses account for approximately $4.1 \times 10^6 m^3$/year while livestock uses are estimated at $8.2 \times 10^6 m^3$.

2. STREAMFLOW REGIME

2.1 BATTLE RIVER NEAR PONOKA, ALBERTA

2.1.1 Consistency of Record

Discharge and stage have been monitored for the Battle River near the town of Ponoka, Alberta, since 7 May 1913, except during the 1932 to 1965 period. Prior to 1966, stage records were obtained manually, generally by daily reading of a staff gauge, while after this time, water levels have been automatically recorded. Any inconsistency in the record between the two periods of observations due to the type of observation is difficult to quantify. However, there is no reason to suspect that any discrepancy would be large as the elevations obtained from the automatic recorders are periodically checked against staff gauge readings with surveying equipment.

Larger sources of inconsistency could arise from relocation of the hydrometric station. This has occurred four times (7 April 1922; 1 May 1925; 16 June 1966; and 7 August 1976) but all sites have been located within a 3 km section of the river and no tributaries occur within this distance. The reasons for the changes in the location of hydrometric station 05FA001 are not readily available but it is apparent that any inconsistency between the 1914 to 1930 and 1967 to 1976 periods due to gauge location would not account for any large difference in recorded flows.

2.1.2 Mean Annual Runoff

The mean annual runoff for the Battle River near Ponoka during the 1914 to 1930 and 1967 to 1976 periods was 112 010 x $10^3 m^3$ and 52 630 x 10^3 m^3, respectively (Table 3). The corresponding flows recorded at Battleford were 268 270 x $10^3 m^3$ and 445 410 x $10^3 m^3$. That is, the flow recorded at the hydrometric station near Ponoka represented approximately 30.4% and 11.8%, respectively, of the total Battle River flows in the two periods. Also, although the flows at Battleford have increased in the latter period, corresponding flows at Ponoka have decreased significantly. The headwater area above Ponoka (1841 km^2) represents approximately 6.0% of the total drainage area (30 820 km^2) yet contributed a disproportionate amount during the early period.

In summary, it is apparent from the analysis of annual flows that the regime of the Battle River has changed and that the change has occurred largely in the headwater region. To evaluate the regime of this river more completely requires an analysis of flows on a monthly basis.

2.1.3 Mean Monthly Flows

The mean, standard deviation, and coefficient of variation of flows of the Battle River near Ponoka are summarized in Table 4. Any significant differences between these data can be detected by the use of standard statistical tests. These tests include the F-test for variances and the t-test for means. In addition, a nonparametric rank test can also be used.

Table 3. Statistics of mean annual flows ($10^3 m^3$), Battle River near Ponoka and at Battleford, 1914 to 1930 and 1967 to 1976.

Station	1914 to 1930			1967 to 1976		
	Mean	S.D.[a]	C_v[b]	Mean	S.D.	C_v
Battle River near Ponoka	112 010	102 380	0.914	52 630 (53% decrease)	87 370	1.650
Battle River at Battleford	368 270	361 660	0.982	445 410 (21% increase)	599 230	1.345

[a] S.D. = Standard Deviation
C_v = Coefficient of Variation

Table 4. Statistics of monthly flows (m^3/s) for the Battle River near Ponoka during the 1914 to 1930 and 1967 to 1976 periods.

Month	1914 to 1930			1967 to 1976		
	Mean	S.D.	C_v	Mean	S.D.	C_v
January	0.67	0.54	0.81	0.15	0.09	0.59
February	0.63	0.59	0.95	0.15	0.10	0.67
March	2.09	3.68	1.76	0.57	0.78	1.36
April	9.34	9.50	1.02	9.75	9.27	0.95
May	8.15	11.83	1.45	3.49	4.29	1.23
June	6.92	7.53	1.09	1.49	1.30	0.87
July	6.24	9.10	1.46	2.14	2.55	1.19
August	1.74	2.16	1.24	1.09	2.05	1.87
September	3.15	6.47	2.05	0.28	0.35	1.26
October	1.65	1.98	1.20	0.28	0.24	0.84
November	0.99	0.97	0.97	0.29	0.19	0.65
December	0.70	0.61	0.86	0.18	0.11	0.65

In the F-test for variances, the null hypothesis (that the variances of the two samples belong to the same population) is either rejected or not rejected at a particular significance level based on the F value as calculated from the ratio of the variances:

$$F = \frac{s_1^2}{s_2^2}$$

where $s_1 > s_2$. If the calculated value is greater than the tabulated value for the given degrees of freedom, then the probability that the difference between the two sample variances is caused by chance is smaller than the specified significance level.

In the t-test, for example, the null hypothesis, means that there is no significant difference between sample means which can either be rejected or not rejected at a particular significance level based on the value of the statistic t. This statistic is calculated from:

$$s_c^2 = \frac{s_1^2 (n_1 - 1) + s_2^2 (n_2 - 1)}{n_1 + n_2 - 2}$$

$$s_d = s_c \frac{n_1 + n_2}{n_1 n_2}$$

where, s^2 = combined or population variance

s_1, s_2 = standard deviations of the two samples

n_1, n_2 = number of data points in each samples

s_d = standard deviation of the difference of means

$\bar{x}_1$, $\bar{s}_2$ = means of the two samples

If the variances are found to be significantly different by use of the F-test, then the variances cannot be pooled. The t-test is then modified to account for these nonhomogeneous variances. The procedure employed in this study is the d-test as illustrated in Kennedy and Neville (1976).

Finally, to complete the statistical analysis of flows, it was decided to utilize a distribution-free or non-parametric test in which it is assumed that the sampling distributions arise from populations with unknown parameters. The Rank Test as outlined by Kennedy and Neville (1976) is an example of such a test. In this method, all the observations for the entire period (for example, January flows for 1914 to 1930 and 1967 to 1976, inclusive) are ranked in increasing order. If no significant difference exists between the two periods, then the sum of the ranks for both samples should be approximately equivalent.

Table 5 summarizes the F-test, t-test, d-test, and Rank Test for the mean monthly flows for the Battle River near Ponoka for the periods 1914 to 1930 and 1967 to 1976 at the 5% significance level. From this table, only in the months of April and August is there no significant difference between the variance of flows while the mean flows are not significantly different in the months of March, April, May, July, August, and September. According to the Rank Tet, flows are not significantly different in the months of January, April, September, November, and December. Therefore, it is apparent that April is the only month which has not undergone significant changes in some aspect or

Table 5. Statistics of monthly flows for the Battle River near Ponoka, 1914 to 1930 versus 1967 to 1976 (5% significance level).

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
F-Test	36.00	34.81	22.26	1.05	7.60	33.55	12.74	1.11	341.72	68.06	26.06	30.75
	S[a]	S	S	N.S.[b]	S	S	S	N.S.	S	S	S	S
d-Test	3.47	2.90	1.59	0.10[c]	1.51	2.86	1.84	0.94[c]	1.84	2.78	2.81	3.22
	S	S	N.S.	N.S.	N.S.	S	N.S.	N.S.	N.S.	S	S	S
Rank	67.0	64.0	80.0	92.0	78.0	52.2	49.0	37.5	32.0	28.0	58.0	56.5
Test	N.S.	S	S	N.S.	S	S	S	S	N.S.	S	N.S.	N.S.

[a] Significant

[b] Not Significant

[c] Indicates t-Test

other according to at least one of the statistical tests employed in this analysis. From Table 4, mean monthly flows (other than in April) have tended to decrease substantially as the coefficient of variation. Thus, the flow regime of the Battle River near Ponoka has changed over the period of record except in the peak snowmelt month of April.

2.2 BATTLE RIVER AT BATTLEFORD, SASKATCHEWAN

2.2.1 Mean Monthly Flows

Analysis of flows for the Battle River at Battleford during 1967 to 1976 required the utilization of flows recorded at Unwin for January, February, November, and December as no records exist for these months at Battleford. The drainage area at Unwin is 25 430 km^2 compared to 30 820 km^2 at Battleford. Examination of the flows at Unwin and Battleford (Tables 6 to 8) indicates that Battleford flows are higher than those recorded at Unwin by an average factor of 1.33 for March to October, inclusive. That is, the drainage area between the two hydrometric stations at Unwin and Battleford contributes on the average an additional 33% more runoff for the same months. However, this figure is highly influenced by March, which has a high ratio, yet accounts for a relatively small percentage of the annual flow. If the total March to October flow at the two sites is considered rather than the average of the monthly ratios, a ratio of 1.22 is obtained. Since this figure is virtually identical to the simple drainage area ratio, it would appear reasonable to use the drainage area ratio to approximate the January, February, November, and December flows during the 1967 to 1976 period at Battleford (Table 9).

Table 6. March to June flows for the Battle River at Battleford and Unwin, 1967 to 1976 (m^3/s).

	MARCH		APRIL		MAY		JUNE	
	A[a]	B[b]	A	B	A	B	A	B
1967	-	0.49	-	3.53	37.53	33.94	16.58	10.09
1968	30.34	12.43	12.57	7.41	5.35	3.59	2.82	1.87
1969	0.59	0.65	86.14	73.69	33.44	28.48	10.47	7.90
1970	0.95	0.85	67.36	57.98	31.69	25.32	13.36	8.93
1971	1.46	1.02	72.38	56.77	50.95	44.32	16.81	12.85
1972	3.42	2.95	42.28	29.66	22.25	20.14	11.90	9.33
1973	4.47	1.78	26.19	29.59	19.56	17.80	19.64	21.25
1974	2.00	1.70	97.85	90.55	280.49	260.07	8.75	68.36
1975	1.61	1.49	15.88	16.66	40.01	51.30	19.99	16.68
1976	2.05	1.01	40.59	29.22	11.67	9.58	11.49	6.73
$\bar{x}$[c]	5.23	2.44	51.25	39.51	53.30	49.46	21.06	16.40
S.D.	9.49	3.58	30.95	28.98	81.00	75.43	23.92	19.03

[a] flows recorded at Battleford

[b] flows recorded at Unwin

[c] $\bar{x}$ = mean

Table 7. July to October flows for the Battle River at Battleford and Unwin, 1967 to 1976 (m^3/s).

	JULY		AUGUST		SEPTEMBER		OCTOBER	
	A[a]	B[b]	A	B	A	B	A	B
1967	6.16	3.78	2.92	1.93	1.27	0.78	1.29	0.78
1968	1.96	1.17	1.99	2.10	2.21	3.29	6.86	5.13
1969	6.34	4.27	3.08	2.18	2.68	2.21	3.14	2.28
1970	27.50	26.48	9.65	6.94	4.64	3.17	3.78	2.75
1971	12.17	10.10	10.38	8.88	5.05	4.20	3.73	2.97
1972	7.52	6.04	5.81	4.40	3.57	2.56	3.37	2.36
1973	21.19	20.50	27.66	27.93	15.82	13.59	8.78	8.41
1974	31.17	25.67	20.15	16.61	11.24	8.83	8.20	6.98
1975	14.36	11.76	6.95	4.91	3.85	2.45	2.72	2.32
1976	6.67	4.38	2.78	1.48	1.66	0.92	1.59	0.88
$\bar{x}$	13.51	11.42	9.14	7.74	5.20	4.20	4.35	3.49
S.D.	9.95	9.47	8.49	8.45	4.68	3.99	2.66	2.54

[a] flows recorded at Battleford

[b] flows recorded at Unwin

Table 8. Ratio of mean Battleford to mean Unwin flows, March to October, 1967 to 1976.

Month	Ratio
MARCH	2.14
APRIL	1.30
MAY	1.08
JUNE	1.29
JULY	1.18
AUGUST	1.18
SEPTEMBER	1.24
OCTOBER	1.25

Table 9. Reconstituted flows at Battleford (m^3/s) based on Unwin flows and a simple drainage area ratio, 1967 to 1976.

YEAR	JANUARY	FEBRUARY	NOVEMBER	DECEMBER
1967	0.88	0.70	0.61	0.35
1968	0.03	0.20	2.35	1.14
1969	0.85	0.88	1.61	1.20
1970	0.93	1.01	3.01	1.70
1971	1.12	1.54	2.54	1.12
1972	0.77	0.82	2.35	0.76
1973	0.59	0.63	5.01	2.80
1974	1.99	2.04	5.34	2.32
1975	1.90	1.65	2.64	1.32
1976	1.33	1.14	0.65	1.08
$\bar{x}$	1.04	1.04	2.61	1.38
S.D.	0.59	0.58	1.57	0.72

The mean, standard deviation, and coefficient of variation of monthly flows are summarized in Table 10 for the Battle River at Battleford. It can be observed that for the 1967 to 1976 period, the mean monthly flows were higher in three months (March, April, and May), lower in six months (January, July, August, September, October, and November), and relatively constant for the remaining three months (February, June, and December) when compared to the 1914 to 1930 period. Also, the coefficient of variation is lower in nine of the months and higher only in March, May, and June. These preliminary observations suggest that there have been no consistent changes in the flow regime of the Battle River at Battleford. This is substantiated from analysis of the statistical tests (Table 11). Only November shows a mean flow which is significantly lower in the more recent period, while the variances of flows are significantly lower in the months of September, October, November, and February, and significantly higher in March, May, and August. Thus, it would appear that, for the Battle River at Battleford, mean monthly flows have not changed significantly over time but there is some tendency for the low-flow months to become more stable while the snowmelt period flows have become more variable.

2.3 SUMMARY

From the analysis of streamflow records which exist for the Battle River near Ponoka and at Battleford and Unwin, it has been demonstrated that mean annual runoff has increased at Battleford while decreasing significantly upstream. With respect to mean monthly flows for Ponoka, April was the only month which did not exhibit any statistically significant changes. In contrast, no consistent changes

Table 10. Statistics of monthly flows (m^3/s) for the Battle River at Battleford during the 1914 to 1930 and 1967 to 1976 periods.

Month	1914 to 1930			1967 to 1976		
	Mean	S.D.	C_v	Mean	S.D.	C_v
January	1.35	1.54	1.14	1.04	0.59	0.56
February	1.03	1.19	1.15	1.04	0.58	0.56
March	1.07	1.27	1.19	5.23	9.49	1.82
April	32.70	22.90	0.70	51.25	30.95	0.60
May	31.64	31.65	1.00	53.30	81.00	1.52
June	20.56	20.31	0.99	21.06	23.92	1.14
July	15.22	16.63	1.09	13.51	9.95	0.74
August	11.25	15.10	1.34	9.14	8.49	0.93
September	8.35	13.40	1.60	5.20	4.68	0.90
October	7.06	10.17	1.44	4.35	2.66	0.61
November	7.32	7.34	1.00	2.61	1.57	0.60
December	1.39	1.05	0.76	1.38	0.72	0.52

Table 11. Statistics of monthly flows for the Battle River at Battleford, 1914 to 1930 versus 1967 to 1976 (α = 5%).

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
F-Test	6.88	4.21	55.49	1.83	6.55	1.39	2.79	3.16	8.19	14.68	21.72	2.13
	S	S	S	N.S.	S	N.S.	N.S.	S	S	S	S	N.S.
t-Test	0.73[a]	0.04[a]	1.78	1.82[a]	0.85[a]	0.06	0.31	0.47[a]	0.89[a]	1.05[a]	2.55[a]	0.04
	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	S	N.S.
Bank			68	91	120	124	134	135	134	139		
Test			S	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.		

[a] Indicates d-Test

in mean monthly runoff could be detected at Battleford. With respect to monthly flow variability for the Battle River near Ponoka and at Battleford from the 1914 to 1930 period to the 1967 to 1976 period, there is a strong tendency for the variability of Battleford flows to be reduced in all months except March, May, and June, which have become more variable, and April which has not shown much change. However, flow variability in the upstream part of the basin has generally decreased in the more recent period, except for April which has remained relatively constant.

In comparing the early period flows near Ponoka and at Battleford, it is evident that the downstream flow variability is higher in three months (January, February, and October), lower in six months (March to May, July, September, and December), and relatively unchanged in June, August, and November. Similarly, for the more recent period, downstream flow variability is higher in three months (March, May, and June), lower in seven months (February, April, July to October, and December), and essentially unchanged in January and November. That is, there appears to be little relationship between flow records at Battleford and those near Ponoka for the periods under investigation.

3. LAKES IN CENTRAL ALBERTA

3.1 INTRODUCTION

Before an analysis can be performed on the possible reasons for lake level variations in central Alberta and the relationship between lake levels and Battle River streamflow, it is necessary to briefly describe the physical characteristics of these lakes and to document the changes that have occurred over time. Nine lakes have been selected within or adjacent to the Battle River Basin on the basis of availability of data. Battle Lake and Pigeon Lake are located within the basin, while Wabamun, Sylvan, Gull, Buffalo, Cooking, Miquelon, and Hastings lakes are situated just outside this watershed. The physical characteristics of these lakes are summarized in Table 12 while Table 13 and Figure 2 illustrate some aspects of the lake level changes.

3.1.1 Wabamun Lake

Wabamun Lake is situated 64 km west of Edmonton at an approximate altitude of 723 m above sea level. It is a relatively small lake having a maximum depth of 11.6 m, a surface area of 82.5 km^2, and a drainage area of 372.4 km^2 (Gallup and Hickman 1973). Lake levels are maintained through precipitation and subsurface flow as there are no significant influent rivers or streams.

Levels have been recorded in 1908 and from 1915 to 1922, 1925 to 1931, and 1933 to the present. In these periods of records, the lake level has varied from 723.66 m in 1927 to 722.30 m in 1962, a maximum elevation change of 1.36 m. In 1978, the lake was 0.53 m below the 1927

Table 12. Physical characteristics of lakes in central Alberta.

Lake	Lake	Drainage Basin	Lake Basin (%)	Elevation[a] (m)	Depth (m)		Maximum Basin Relief (m)	Maximum Length (km)	Maximum Width (km)	Storage Capacity (106 m^3)
					Max.	Mean				
Wabamun	82.5	372.4	22.2	722.7	11.6	5.4	85	19.2	6.6	455
Battle	4.5	103.6	4.3	836.7	-	7.3	122	6.4	0.8	12
Pigeon	95.9	283.6	33.8	849.5	9.8	6.1	80	16.1	7.7	598
Sylvan	42.5	126.3	33.7	935.7	18.3	9.6	175	12.9	3.2	409
Gull	80.0	270.0	29.6	899.2	8.5	3.4	92	16.9	6.1	415
Buffalo	84.0	1530.0	5.5	780.0	6.7	2.8	195	16.6	7.9	235
Miquelon	13.2	85.7	15.4	762.6	4.6	2.9	38	5.2	3.2	24
Cooking	34.4	210.3	16.4	735.8	4.6	2.6	39	10.9	6.1	48
Hastings	8.3	89.9	9.2	735.5	-	-	38	6.5	1.8	-

[a] above sea level.

Table 13. Changes in levels of lakes in central Alberta.

Lake	Years of Data			Maximum Recorded Level		Minimum Recorded Level		Maximum Change(m)	1978 Level-- Maximum Recorded(m)	Greatest Annual Change	
	Recorded	Estimated	Total	Elevation(m)	Year	Elevation(m)	Year			Amount(m)	Year
Wabamun	62	-	62	723.66	1927	722.30	1962	1.36	-0.53	0.74	1965
Battle	16	-	16	837.98	1965	836.10	1974	0.98	-0.02	0.82	1974
Pigeon	38	-	38	850.98	1927	849.33	1968	1.65	-0.81	0.70	1948
Sylvan	40	-	40	937.24	1955	935.89	1939	1.35	-0.79	0.49	1965
Gull	37	-	37	901.45	1924	898.54	1977	2.91	-2.85	0.39	1967
Buffalo	23	3	26	781.20	1975	779.49	1964	>1.71	-0.78	+0.83	1974
Miquelon	15	5	20	762.91	1965	761.80	1978	>1.11	-1.11	0.27	1977
Cooking	23	5	28	736.52	1956	735.25	1971	>1.27	-0.55	0.51	1959
Hastings	29	-	29	736.55	1965	735.24	1971	1.31	-0.60	0.36	1974

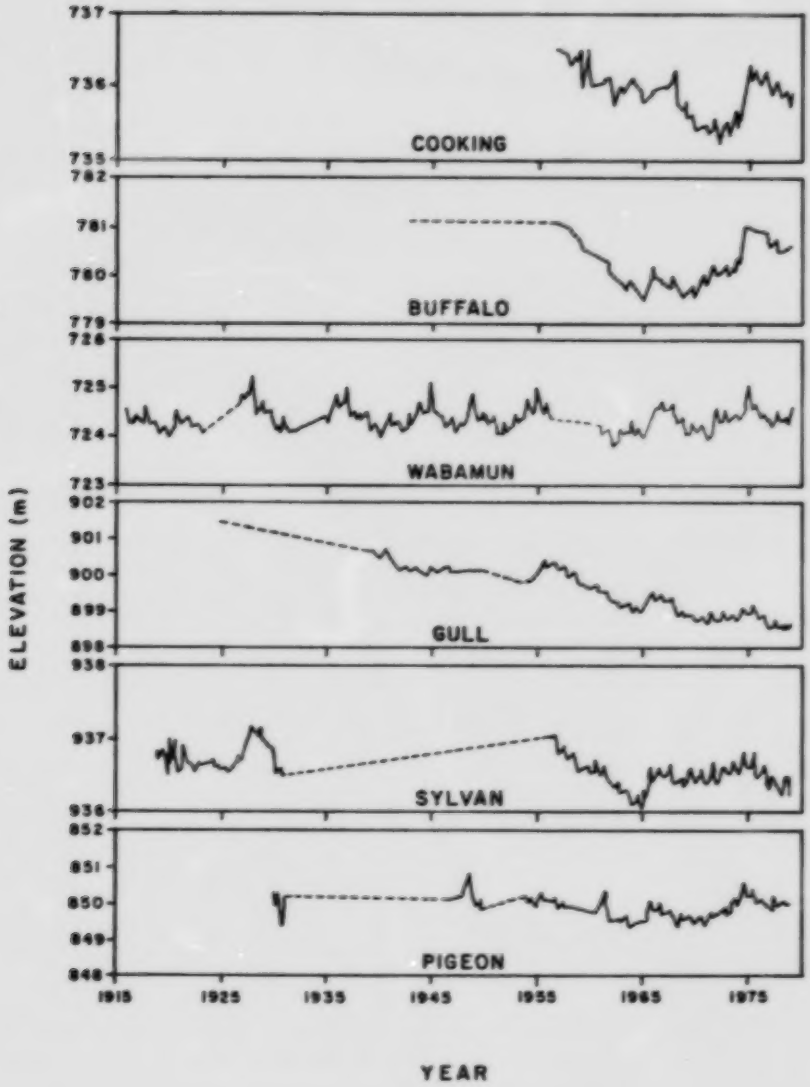

Figure 2. Lake level variations for lakes in central Alberta (scale is not constant).

level. The largest yearly change occurred in 1965 when the lake varied from 724.02 m to 724.74 m, a difference of 0.72 m.

There would appear to be a 9 to 10 year cycle in the peak lake levels (1927, 1936, 1944, 1948, 1954, 1965, and 1974). The peak in 1974 is slightly higher than in 1908 and 1954 but not quite as high as in the highest years of 1927 and 1944. The low level recorded in 1970 is not as low as that recorded in 1961 and 1964 and has been almost equalled in 4 years (1919, 1931, 1939, and 1950).

3.1.2 Battle Lake

Battle Lake, located about 55 km west of Wetaskiwin and 115 km southwest of Edmonton, is situated in a narrow 75 m deep valley near the drainage divide between the North Saskatchewan and Battle River systems. It is approximately 6.4 km long and about 800 m wide. The surface area is 4.5 km^2 and the mean depth is 7.3 m (Battle River Regional Planning Commission 1974). The drainage area of the lake is approximately 103.6 km^2 and the maximum relief in the basin is about 122 m. Most of the watershed is heavily treed with little agricultural development.

Available data (1961 to 1978) indicate that the level of Battle Lake has been relatively constant. The maximum recorded variation in 1 year is 0.82 m and the median variation is only 0.14 m. The maximum recorded level is 837.08 m and the minimum 836.10 m, a variation of 0.98 m.

3.1.3 Pigeon Lake

Pigeon Lake is situated approximately 10 km east of Battle Lake at an approximate altitude of 850 m above sea level. It is the largest lake within the study area, having a maximum length of 16.1 km and maximum width of 7.7 km. The maximum relief within this lake basin is approximately 80 m with most of the surrounding countryside being heavily wooded. A small creek at the south end drains the lake during high stages.

Thirty-eight years of record are available for Pigeon Lake (1924 to 1931, 1946 to 1949, 1952 to 1972, 1974 to 1978). During this time, the lake level has varied from a maximum of 850.98 m (1927) to a minimum of 849.33 m (1968), a maximum variation of 1.65 m. In 1978, the level was 0.81 m lower than the highest recorded, and the largest annual change occurred in 1948 when the lake went from 850.71 m to 850.01 m, a difference of 0.70 m.

3.1.4 Sylvan Lake

Sylvan Lake, located 24 km west of Red Deer, is situated in a shallow basin. Hills to the west and east rise to an elevation of 1020 m while those to the northeast reach 1110 m. The elevation of the lake is 930 m. Inflow to the lake is through numerous springs and minor intermittent creeks. A high-water outlet is located to the southeast. The lake is 12.9 km long and 3.2 km wide with a total surface area of 42.5 km^2. The maximum depth is 18.3 m (Shaw 1974).

Records for Sylvan Lake are available for 1918 to 1922, 1924 to 1930, 1939 to 1941, and 1955 to 1978. In this period, the highest level (937.24 m) was recorded in 1955 and the lowest (935.89 m) in 1939,

a variation of 1.35 m in 17 years. The greatest annual change occurred in 1965 when the lake varied from 936.05 m to 936.54 m., or 0.49 m. From 1955 to 1978, the lake level declined 0.79 m. This is equivalent to an average annual decrease of less than 0.03 m. However, during this time, the lake level decreased at the rate of 0.12 m per year from 1955 to 1964, recovered sharply in 1965, and has remained relatively constant since that time.

3.1.5 Gull Lake

Gull Lake, located less than 16 km west of Lacombe, with clean, broad sand beaches and clear water is one of the most popular summer recreational lakes in Alberta. The lake occupies approximately 80 km^2 of a total drainage area of 270 km^2. The maximum basin relief is approximately 92 m.

Of the lakes in central Alberta, Gull Lake has exhibited one of the greatest declines in water level. The highest recorded level was 901.45 m in 1924 while the lowest was 898.54 m in 1977, a difference of 1.91 m. The total decline to 1978 is 1.85 m, with the greatest annual change occurring in 1967 when the level varied from 899.32 to 898.93 m or 0.39 m.

The period of most rapid decline occurred between 1955 and 1963 when the lake level dropped 1.40 m or 0.16 m per year. From 1963 to 1978, the level has continued to recede another 0.37 m or 0.02 m/year.

3.1.6 Buffalo Lake

Buffalo Lake is situated approximately 48 km east of Lacombe and 16 km northwest of Stettler. This lake is fed from the northwest by Spotted Creek and Parlby Creek which flow together into Spotted Lake and then drain into Buffalo Lake. The total drainage area of Buffalo Lake is estimated at 1530 km^2 of which 735 km^2 drain the area downstream from Spotted Lake. The outlet from Buffalo Lake (Tail Creek) is located at the southwest end but remains dry most of the time and was dry during the period 1958 to 1974.

Buffalo Lake itself has a surface area of approximately 84 km^2, while smaller lakes within the Buffalo Lake Basin add another 16 km^2 to the total lake area. The average depth of the main lake is only 3 m while the maximum depth is approximately 7 m. The surface elevation is approximately 780 m.

Records exist for Bufalo Lake near Stettler for 1942 and 1956 to 1978, a total of 23 years. Written accounts indicate that discharge from the lake occurred during the 1905 to 1910, 1915 to 1919, and possibly the 1927 to 1929 periods. That is, lake levels at these times were greater than 782.27 m, which, compared to the highest recorded level (1975) of 781.20 m, is at least 1.07 m higher. The level recorded in 1978 was 780.42 m and the lowest on record was 779.49 which was recorded in 1964. This represents a maximum decline in lake level in excess of 2.78 m. The greatest annual change in water level occurred between May of 1973 and May of 1974 when the lake increased by 0.82 m.

The lake level recorded in 1974 is approximately equal to that recorded in 1956 and 1942 which might suggest a peak cyclicity of

approximately 14 to 18 years. The lowering of lake level during the 1956 to 1964 period, recovery in 1965, and recession to 1969 is very similar to Wabamun, Pigeon, and Gull lakes. However, the strong recovery to former high lake levels is more characteristic of Wabamun, Pigeon, and Cooking lakes.

3.1.7 Miquelon Lakes

Miquelon Lakes are located approximately 65 km southeast of Edmonton and 19 km north of Camrose. The lakes occupy an area within the Cooking Lake Moraine whose topography is characterized by knobs and kettles formed from stagnant ice. Elevations within the drainage area vary from 746.8 m southwest of the lakes to highs in excess of 800 m south and east of the main lake (Battle River Regional Planning Commission 1973).

Drainage within the watershed goes from Miquelon Lakes, which, at an elevation of 762.6 m, are the highest lakes in this region, through Larry Lake to Oliver Lake, then to Ministik, Cooking,and Hastings lakes, and eventually to Beaverhill Lake via Hastings Creek. Presently, Miquelon Lakes exist as three separate water bodies, whereas in 1917, one large lake occupied a surface area of 28 km^2. In 1967, the surface area of the three lakes was 13.2 km^2. The largest lake extends 5.2 km in length and 3.2 km in width with a surface area of 8.7 km^2 and a capacity of 24 x 106 m^3. The maximum depth is 4.6 m and the mean depth is 2.9 m (EPEC Consulting Ltd. 1971). The watershed area is 85.7 km^2.

Lake level records indicate that the lake has declined 5.52 m from an estimated level of 768.10 in 1901 (Battle River Regional

Planning Commission 1973) to a low of 762.58 m recorded in 1972 (Alberta Environment 1976). The recorded level in 1978 was 762.25 m.

3.1.8 Cooking Lake

Cooking Lake, located north and west of Miquelon Lakes, lies at an elevation of 735.9 m (1978 data). The total drainage area is 210.3 km^2 and the lake surface occupies 34.4 km^2. The average depth is approximately 2.6 m while the maximum depth is approximately 4.6 m. The length of the main part of the lake is 10.9 km while the maximum width is 6.1 km.

Recorded lake levels exist for the following years: 1919 to 1922; 1939; 1941; 1956 to 1978. In addition, approximate levels for years in which no measurements were taken were determined by more indirect methods (Alberta Environment 1976). For example, the 1916 lake area was calculated from maps of a legal survey carried out at that time and the approximate level related to known area-elevation data. This was repeated for 1950 from aerial photographs taken of the moraine area. Approximate levels in 1897, 1951, and 1952 were obtained from comments by long time residents of the Cooking Lake area.

Lake levels declined from an estimated 738.25 m in 1897 to the estimated level of 735.48 m in 1951, then rose to 736.52 m in 1956. Since this time, the lake has remained below that level with a low of 735.25 m being experienced in 1971. The November 1978 reading was 735.97 m.

3.1.9 Hastings Lake

Hastings Lake is located less than 3.2 km east of Cooking Lake and south of the town of Deville. Its elevation (1978) is 735.0 m with a drainage area of 89.9 km^2. The lake occupies an area of 8.3 km^2.

Records of lake levels exist for 1919 to 1922, 1939, 1941, 1949, 1956 to 1962, and 1964 to 1974. The lowest recorded level was 733.39 m in 1949 and the maximum level was 736.42 m in 1974. The earliest reading on record (1919) was 735.37 m. Therefore, it is apparent that of all the lakes with records in central Alberta, Hastings Lake is anomalous insofar as present levels are the highest on record.

3.2 LAKE LEVEL TRENDS

In an attempt to detect trends in lake levels and regional similarities between the lakes in the study area, moving-mean, linear trend, and correlation analysis were applied. The results of these analyses are indicated in the following section.

3.2.1 Moving-mean Analysis

For moving mean analysis of lake levels, it is apparent that incomplete records may limit the usefulness of this technique in detecting regularities in lake level pattern. That is, any missing year of record in a sequence would break that sequence. Also, it was hoped that the cyclicity of the highest recorded annual levels as well as the lowest on record for each year could be determined by this technique. However, an examination of the record of each of the study lakes shows that the highest and lowest levels may occur in any of several months depending on such physical factors as winter precipitation total, rate

of snowmelt, quantity and distribution (temporal and spatial) of summer rain, and evaporation, as well as the number of days of record in each year. For example, Sylvan Lake has recorded annual maximum levels in the months of March, May, June, July, August, September, October, and November, and annual minimum levels in February, March, April, May, July, August, September, October, and November. As a further example, only 2 d of records are available for Sylvan Lake in 1923. The maximum for the year was recorded on 23 November at an elevation of 936.70 m, while the minimum was recorded on 19 June at 936.65 m.

Therefore, it was decided to select a certain time of year to see how the water levels varied from year to year for each of the nine study lakes. Again, from an examination of the lake level records, it was evident that in most years, records were obtained near the beginning of summer and prior to freeze-up. The reason for this is not clear, but may relate to the thought that the highest and lowest levels can be detected at these two times, respectively. (Table 14 illustrates that to some degree, at least, this assumption may be valid. However, caution should be exercised in extending this to a general statement of lake level changes). Accordingly, the months of May and October were selected as being indicative of changes in lake elevation. Wherever possible, these two months were used but some tolerance was allowed if no records existed at these times. For example, it was felt that late April or June records could be substituted for May (this only occurred 44 times out of a total possible 283 lake-years of record for all the study lakes combined), and that late August, September, or November would be acceptable for October (83 times out of 283 lake-years of

Table 14. Summary of lake level records for lakes in central Alberta.

Lake	Years of Record	Years With May Records	%	Years With October Records	%	Years With April to June Records	%	Years With Late Aug. to Nov. Records	%
Battle	16	12	75	5	31	14	88	15	94
Buffalo	23	11	48	3	13	14	61	14	61
Cooking	23	17	74	15	65	21	91	18	78
Gull	37	22	59	14	38	30	81	31	84
Hastings	29	18	62	12	41	22	76	16	55
Miquelon	15	12	80	11	73	13	87	14	93
Pigeon	38	22	58	13	34	32	84	30	79
Sylvan	40	28	70	20	50	37	93	36	90
Wabamun	62	54	87	55	89	57	92	58	94

record). It was felt that the greater tolerance for October is acceptable since evaporative losses and runoff are usually quite low at this time of year.

Finally, a 5 year moving mean was selected as 10 years would have rendered the lake level records virtually unusable due either to years with complete missing records or to the inability to conform to the May or October periods of analysis. With this aproach, it was possible to compute the moving means for the lakes indicated in Appendix 8.1, Tables 48 to 54.

Cooking, Gull, Hastings, Pigeon, and Wabamun lakes show similarities in moving mean levels with lake levels declining until 1970 or 1971, then recovering slightly in the next few years, and again declining in the last couple of years of record. The second decline started in 1976, 1973, 1977, 1976, and 1974, for each lake, respectively. Sylvan Lake also exhibits a slow decline after about 1974 but moving mean lake levels had risen from 1963 to 1974. The levels have also tended to be more constant than for the other lakes. Battle Lake levels decreased to a low in 1973 but rose to a high in 1978, thus showing no trend toward declining levels in the last 2 or 3 years. Finally, Wabamun Lake appears to exhibit a 10 to 12 year cycle in the earlier period (1936 to 1955), with perhaps a similar pattern in the more recent period (low in 1970, rise to 1974, and decline to 1978).

3.2.2 Linear Trend Analysis

To detect whether there is any trend to lake levels for Gull, Sylvan, Pigeon, and Wabamun lakes, linear trend analysis was performed on May, October, annual maximum, and annual minimum recorded lake levels. The results of this analysis are summarized in Table 15.

The trends for Gull Lake are all negative indicating that the lake level has declined over time. For the entire period of record this rate of decline has varied from 59 mm to 74 mm per year. However, since 1953, the average annual decline in maximum and minimum recorded lake levels is approximately half of the decline observed prior to this date. This indicates that there may have been a tendency for this lake to have recovered.

Sylvan Lake levels have declined annually at an average rate of 8 to 11 mm per year over the entire period of record. These declines are similar to those observed for Pigeon Lake which had an average annual decline of 5 to 7 mm. However, whereas the regression coefficients are statistically significant for Sylvan Lake, they are not significant for Pigeon Lake. The standard error of estimate, which is a measure of the variability of the data points, is low for Sylvan Lake and higher for the other lake. This indicates that Sylvan Lake levels have not fluctuated as much as those of Pigeon Lake.

The data for Wabamun Lake indicate that lake levels have remained essentially constant over time. Thus, present levels are as high or higher than those recorded in the 1930's. Although there are relatively large variations in water elevation, these are of relatively

Table 15. Summary of linear trend equations for levels of lakes in central Alberta.

LAKE	LAKE LEVEL	YEARS OF RECORD	REGRESSION COEFFICIENT	SIGNIF. LEVEL	INTERCEPT	SLOPE	S.D. OF SLOPE
Gull	May	31	-0.942	<1%	900.55	-0.065	0.009
	Oct.	31	-0.928	<1%	900.56	-0.074	0.010
	Max.	37	-0.937	<1%	900.79	-0.059	0.008
		1924-1952	-0.818	<1%	901.07	-0.114	0.025
		1953-1978	-0.908	<1%	900.81	-0.060	0.013
	Min.	37	-0.952	<1%	900.74	-0.065	0.007
		1924-1952	-0.835	<1%	902.03	-0.123	0.011
		1953-1978	-0.934	<1%	900.76	-0.065	0.012
Sylvan	May	34	-0.405	5%	936.77	-0.008	0.008
	Oct.	35	-0.598	<1%	936.68	-0.011	0.006
	Max.	36	-0.463	<1%	936.85	-0.009	0.007
	Min.	36	-0.566	<1%	936.70	-0.011	0.007
Pigeon	May	28	-0.160	N.S.	849.99	-0.006	0.013
	Oct.	27	-0.148	N.S.	849.87	-0.005	0.013
	Max.	33	-0.249	N.S.	850.10	-0.007	0.010
	Min.	33	-0.266	N.S.	849.90	-0.007	0.009
Wabamun	May	53	0.013	N.S.	724.44	0.000	0.004
	Oct.	55	0.056	N.S.	724.29	0.001	0.004
	Max.	57	0.000	N.S.	724.51	0.000	0.004
	Min.	57	-0.092	N.S.	724.28	-0.001	0.004

short duration. This suggests that this lake is responding perhaps to water budget changes but not to any physical changes in basin characteristics.

The apparent discrepancy that minimum lake levels can be greater than either October or May levels for some of the lakes can be explained partly by the different periods of record available for each parameter. For example, not every year provided a May or October reading whereas a single reading in a particular year would be both a maximum and a minimum value for that year. Also, not all May levels are maximum values and some of these are not much higher than the minimum for that year.

3.2.3 Correlation Analysis

In an attempt to discern regional similarities between the lakes in the study area, it was decided to evaluate the correlation coefficients of maximum lake levels. The values of R for Sylvan, Pigeon, Gull, Buffalo, Cooking, and Wabamun lakes are shown in Table 16 along with the appropriate years of records. The only significant correlations were for Pigeon-Buffalo, Pigeon-Wabamun, Wabamun-Buffalo, and Pigeon-Sylvan. The probable reason for the poor correlations is due to the fact that maximum levels were not always recorded in the same months for all lakes.

The correlation coefficients for maximum lake levels for Cooking versus Miquelon, Cooking versus Hastings, and Miquelon versus Hastings lakes were 0.650, 0.833, and 0.803, respectively, for the period 1964 to 1978. These correlations suggest that these three adjacent lakes are responding to regional effects.

Table 16. Correlation coefficients of maximum annual levels for selected lakes in central Alberta.

PERIOD	LAKES	R	SIGNIFICANCE LEVEL (%)
1961 to 1978	Pigeon vs. Buffalo	0.874	5
1959 to 1978	Pigeon vs. Wabamun	0.646	5
1961 to 1978	Wabamun vs. Buffalo	0.624	5
1959 to 1978	Pigeon vs. Sylvan	0.604	5
1961 to 1978	Buffalo vs. Sylvan	0.539	5
1959 to 1978	Cooking vs. Gull	0.535	5
1959 to 1978	Sylvan vs. Wabamun	0.506	5
1959 to 1978	Cooking vs. Pigeon	0.332	-
1961 to 1978	Cooking vs. Buffalo	0.305	-
1959 to 1978	Gull vs. Sylvan	0.073	-
1959 to 1978	Sylvan vs. Cooking	0.030	-
1959 to 1978	Cooking vs. Wabamun	0.002	-
1959 to 1978	Gull vs. Pigeon	-0.135	-
1959 to 1978	Gull vs. Wabamun	-0.322	-
1961 to 1978	Gull vs. Buffalo	-0.381	-

From the graphs of lake level versus time for Pigeon, Buffalo, Wabamun, Sylvan, and Gull, general trends can be observed and have been noted in the section of this report dealing with the physical description of the lakes. However, it is difficult to analyze the complete sequences of lake level data due to the relatively short and incomplete records of most lakes. But from visual observation of the 1956 to 1978 period, it would appear that certain similarities exist for many of these lakes in the 1956 to 1966 and 1967 to 1978 sub-periods, although correlations for the entire period may be generally low. With this qualitative observation in mind, it was decided to evaluate the mean annual lake level correlation coefficients for these sub-periods. Mean annual levels were obtained by graphical integration of lake levels versus time (Appendix 8.2, Tables 55 to 59). The results of the analysis are shown in Table 17.

In the earlier sub-period, all the correlations were significant except Gull-Wabamun and Buffalo-Wabamun. The poorest correlations were with Wabamun Lake which seems to indicate that this lake does not respond to the same influences as lakes closer to and within the Battle River Basin. That is, Gull, Buffalo, Sylvan, and Pigeon lakes appear to be responding to regional effects of climate, land use, and geology, and not on an individual lake basis.

In the latter sub-period, the correlations were significant only for Pigeon-Buffalo, Pigeon-Wabamun, Buffalo-Wabamun, and Sylvan-Gull, and in general, tended to be lower than in the previous sub-period. For example, the correlations were higher in the latter period only for Pigeon-Buffalo, Pigeon-Wabamun, and Buffalo-Wabamun. The

Table 17. Correlation coefficients of mean annual levels for selected lakes in central Alberta.

PERIOD	LAKES	R	SIGNIFICANCE LEVEL (%)
1957 to 1966	Gull vs. Buffalo	0.992	1
1956 to 1966	Gull vs. Sylvan	0.966	1
1956 to 1966	Sylvan vs. Pigeon	0.952	1
1957 to 1966	Sylvan vs. Buffalo	0.928	1
1956 to 1966	Gull vs. Pigeon	0.921	1
1957 to 1966	Pigeon vs. Buffalo	0.863	1
1956 to 1966	Pigeon vs. Wabamun	0.816	1
1956 to 1966	Sylvan vs. Wabamun	0.639	5
1956 to 1966	Gull vs. Wabamun	0.549	-
1957 to 1966	Buffalo vs. Wabamun	0.340	-
1967 to 1978	Pigeon vs. Buffalo	0.965	1
1967 to 1978	Pigeon vs. Wabamun	0.841	1
1967 to 1978	Buffalo vs. Wabamun	0.712	1
1967 to 1978	Gull vs. Sylvan	0.626	5
1967 to 1978	Sylvan vs. Wabamun	0.549	-
1967 to 1978	Sylvan vs. Pigeon	0.410	-
1967 to 1978	Gull vs. Wabamun	0.262	-
1967 to 1978	Sylvan vs. Buffalo	0.192	-
1967 to 1978	Gull vs. Pigeon	-0.111	-
1967 to 1978	Gull vs. Buffalo	-0.389	-
1957 to 1978	Pigeon vs. Buffalo	0.866	1
1956 to 1978	Pigeon vs. Wabamun	0.778	1
1957 to 1978	Sylvan vs. Buffalo	0.644	1
1956 to 1978	Gull vs. Sylvan	0.577	1
1956 to 1978	Sylvan vs. Wabamun	0.565	1
1956 to 1978	Sylvan vs. Pigeon	0.523	5
1957 to 1978	Buffalo vs. Wabamun	0.498	5
1957 to 1978	Gull vs. Buffalo	0.274	-
1956 to 1978	Gull vs. Wabamun	0.046	-
1956 to 1978	Gull vs. Pigeon	-0.011	-

reasons for the shift in correlation coefficients from one period to the next are not apparent but could relate to small changes in climatic parameters between these two sub-periods. Verification of this possibility has not been attempted in the present study and would be extremely difficult due to the lack of detailed climatic data.

The correlations of mean annual lake levels for the entire 1956 to 1978 period were significant for Pigeon-Buffalo, Pigeon-Wabamun, Sylvan-Buffalo, Gull-Sylvan, Sylvan-Wabamun, Sylvan-Pigeon, and Buffalo-Wabamun. The only lakes which exhibited significant correlations for both sub-periods as well as the total period were Pigeon-Buffalo, Pigeon-Wabamun, and Gull-Sylvan. It would appear that the regional similarity between Pigeon, Buffalo, Gull, and Sylvan, in the 1956 to 1966 period, has been replaced by regional variations on a smaller scale, although it is most interesting to note that Sylvan and Gull lake levels are in considerable agreement during both sub-periods, as well as during the entire 1959 to 1978 period, and that these lakes do not appear to be independent of each other.

As a point of interest, Table 18 summarizes the statistics of mean annual lake levels for Gull, Sylvan, Pigeon, Buffalo, and Wabamun from 1953 to 1978. These results are consistent with the previous correlation analysis. For example, in the period from 1956 to 1966, both Gull Lake and Sylvan Lake responded in a similar fashion with Gull Lake dropping 0.92 m and Sylvan Lake 0.42 m. After 1966, Gull Lake decreased an additional 0.72 m while Sylvan Lake decreased only 0.16 m. Since both lakes exhibited similar trends, the correlation coefficient, 0.966, is understandably high. However, in the 3 year period from 1967

Table 18. Statistical summary of mean annual lake levels, Gull, Sylvan, Pigeon, Buffalo, and Wabamun lakes, 1953 to 1978 (α = 5%).

	GULL 1955 to 1966	SYLVAN 1956 to 1966	PIGEON 1953 to 1966	BUFFALO 1957 to 1966	WABAMUN 1953 to 1966
$\bar{x}$	899.60	936.49	849.79	900.22	722.84
x^{2}[a]	0.190	0.063	0.060	0.218	0.071
	1967 to 1978	1967 to 1978	1967 to 1978	1967 to 1978	1967 to 1978
$\bar{x}$	898.79	936.48	849.85	900.66	722.87
x^{2}	0.017	0.009	0.101	0.190	0.028
F-test	11.18	7.00	1.68	1.15	2.54
	S	S	N.S.	N.S.	N.S.
t-test	6.17[b]	0.12[b]	0.53	0.20	0.34
	S	S	N.S.	N.S.	N.S.

[a] s^{2} = variance

[b] indicates d-test

to 1969, Gull Lake levels declined 0.51 m while Sylvan Lake decreased by only 0.06 m. Sylvan Lake showed no appreciable change in 1967, a slight decrease in 1968, and recovery in 1969, while Gull Lake decreased in all three years. Also, Sylvan Lake elevation recovered in 1971 while Gull Lake declined slightly. These differences account for the lower correlation coefficient (0.626) between the two lakes in the 1967 to 1978 period and also explain why Gull Lake levels have decreased significantly from the 1955 to 1966 period to the present while Sylvan Lake has not.

3.3 SUMMARY

From the 5 year moving mean analysis of lakes in central Alberta, Cooking, Gull, Hastings, Pigeon, and Wabamun show similarities, with levels declining in the last few years. Battle Lake is dissimilar as there is no trend toward declining levels in the last 2 or 3 years. Sylvan Lake levels were rising from 1963 to 1974 while most of the other lakes were receding.

From linear trend analysis, it was concluded that: (1) the rate of decline of Gull Lake has decreased substantially; (2) present Sylvan Lake levels are similar to the early record; (3) Pigeon Lake levels have risen in the last 15 to 20 years; and (4) Wabamun Lake levels have been relatively constant over time.

Finally, with respect to Gull Lake, significant correlations exist in mean annual lake levels for the 1956 to 1966 period with Buffalo, Sylvan, Pigeon, and Wabamun, but only with Sylvan Lake in the 1967 to 1978 and 1956 to 1978 periods.

4. CLIMATIC CHANGE

4.1 INTRODUCTION

From the analysis of the streamflow regime of the Battle River near Ponoka, it has been shown that the major changes in flow have occurred largely in the non-winter months and that the flow characteristics in the peak snowmelt month of April have not changed significantly. This implies that winter precipitation has been relatively constant from the 1914 to 1930 period to the present but that the summer precipitation regime may have changed.

The high degree of correlation between the lake elevation records obtained during the ice-free period of many of the lakes of central Alberta suggests that the lakes are responding to regional processes. This implies that these lakes may be responding to variations in non-winter climatic parameters. Therefore, in order to understand the relationships between changes in streamflow, lake levels, and climate of the Battle River Basin, it is necessary to examine the non-winter climatic variables which may have undergone changes from the 1914 to 1930 period to the present.

The selection of the appropriate climatic parameters to include in an analysis of the relationships between climatic and hydrologic changes is difficult. This is due partly to the paucity of climate records both in a temporal and spatial sense, and partly to the complex relationships between climate, streamflow, and variations in lake levels. Fortunately, for the Battle River Basin, climate records exist during the period of analysis for Lacombe (Station Number 3023720), Wetaskiwin (Station Number 3017280), and Battleford (Station

Number 4045600). Other climate data recorded at stations such as Ponoka have not been utilized in the present study because of their incompleteness.

Since it was not apparent whether changes in streamflow and lake levels have responded to short- or long-term precipitation changes, it was decided to initially examine monthly precipitation records at Lacombe, Wetaskiwin, and Battleford. More detailed daily precipitation analysis was then carried out using the May to September records at Lacombe and Wetaskiwin only as it has been concluded that most of the hydrological changes have occurred in the upstream part of the Battle River Basin. The variables examined include average storm intensity, average storm duration, and average storm frequency for each of the five summer months. Decreases in average storm intensity and frequency of occurrence should be reflected in lower runoff and gradual declines in lake elevations. A longer average storm duration should produce similar results if, as is commonly accepted, precipitation intensity and duration are inversely related. Finally, to complete the precipitation analysis, maximum one-day, two-day, three-day, and four-day precipitation amounts were determined in each of the summer months for the 1914 to 1930 and 1967 periods at both Lacombe and Wetaskiwin. It is possible that the hydrological regime of the Battle River watershed may be responding to maximum precipitation as well as to average daily and monthly values.

Evaporative losses from lakes and soil surfaces may be sensitive to changes in summer air temperature over the period of record. As an index of temperature, it was decided to utilize the

concept of growing-degree days using a base of 5°C. Increases in growing-degree days may partly explain any declining trends in lake elevation. For this part of the analysis the records at both Lacombe and Wetaskiwin were examined.

Finally, the statistical tests utilized include the F-test for variances, the t-test for means, and a rank test. A discussion of the actual relations between changes in climate, streamflow, and lake levels will be undertaken in Section 5.

4.2 PRECIPITATION REGIME

4.2.1 Monthly Precipitation

The statistics of monthly precipitation for Lacombe, Alberta, are summarized in Tables 19 and 20. From these tables, it can be observed that there are no statistically significant changes in either the means or variances of the non-winter months. Furthermore, since these two parameters have increased and decreased in a random fashion from the 1914 to 1930 period to the more recent period, there is no consistent trend in either precipitation magnitude or variability.

Tables 21 and 22 summarize the analysis of monthly, winter, and non-winter precipitation recorded at Wetaskiwin, Alberta. The results for this station are very similar to those observed for Lacombe, with no noticeable trends shown by the data.

Finally, from the analysis of monthly precipitation recorded at Battleford, Saskatchewan (Tables 23 and 24), it is observed that the mean precipitation is not significantly different from one period to the next, although there is a slight trend towards higher precipitation

Table 19. Mean, variance, and coefficient of variation for monthly precipitation (mm), Lacombe.

	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
						1914 to 1976						
$\bar{x}$	18.3	16.0	18.8	25.7	41.9	80.0	68.6	64.5	40.9	19.6	18.5	21.8
s^2	174.5	103.2	119.3	264.3	466.1	2684.6	1228.6	1530.1	898.3	281.0	240.1	272.6
C_v	0.72	0.63	0.58	0.63	0.52	0.65	0.51	0.61	0.73	0.86	0.84	0.76
						1914 to 1930						
$\bar{x}$	16.0	16.5	19.6	28.7	47.0	74.4	65.3	64.3	47.0	18.3	19.8	20.6
s^2	98.1	108.5	136.5	264.3	488.3	3295.2	1175.8	1413.2	929.0	256.1	316.1	382.5
C_v	0.62	0.63	0.60	0.57	0.47	0.77	0.53	0.58	0.65	0.88	0.90	0.95
						1967 to 1976						
$\bar{x}$	22.4	15.2	17.5	20.8	33.8	89.7	74.7	65.0	30.5	22.1	16.5	23.6
s^2	298.3	93.2	93.2	248.0	343.8	1735.2	1394.1	1998.4	724.9	343.8	124.9	98.1
C_v	0.77	0.63	0.55	0.76	0.55	0.46	0.50	0.69	0.88	0.84	0.68	0.42

Table 20. Statistical analysis summary of monthly and seasonal precipitation, 1914 to 1930 versus 1967 to 1976, Lacombe (α = 5%).

	MONTHLY PRECIPITATION											
	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
F-test	3.00	1.17	1.45	1.07	1.42	1.90	1.17	1.47	1.29	1.32	2.46	3.99
	S	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	S
t-test	1.11[a]	0.38	0.46	1.24	1.59	0.73	0.67	0.03	1.43	0.56	0.51	1.72[a]
	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Rank Test	122.5	129.0	130.5	117.0	115.0	110.0	126.0	128.0	109.0	133.0	138.0	110.0
	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

	SEASONAL PRECIPITATION	
	WINTER (1 NOV. to 28 FEB.)	NON-WINTER (1 MAR. to 31 OCT.)
F-test	5.15	2.50
	S	N.S.
t-test	0.41[a]	1.12
	N.S.	N.S.

[a] Denoted t-test for Non-Homogeneous Variance (d-test).

Table 21. Mean, variance, and coefficient of variation for monthly precipitation (mm), Wetaskiwin.

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
	1914 to 1976											
$\bar{x}$	28.2	21.8	28.2	24.9	35.8	87.4	82.0	57.4	35.6	21.6	20.1	25.9
s^2	307.2	382.5	202.3	444.5	570.1	1953.3	1672.3	1124.1	711.3	264.3	174.5	423.3
C_v	0.62	0.90	0.50	0.85	0.67	0.51	0.50	0.58	0.75	0.75	0.66	0.79
	1914 to 1930											
$\bar{x}$	24.9	24.9	27.2	29.0	41.9	70.4	69.3	56.4	40.9	19.3	19.3	25.9
s^2	217.0	658.1	181.2	511.0	645.2	752.5	1375.2	976.1	2232.0	372.6	217.0	738.6
C_v	0.59	1.03	0.50	0.78	0.61	0.39	0.53	0.55	1.16	1.00	0.76	1.05
	1967 to 1976											
$\bar{x}$	31.5	18.5	29.5	20.3	29.2	106.9	96.5	58.4	29.5	23.9	20.8	25.9
s^2	423.3	98.1	248.0	372.6	466.1	2818.1	1799.3	1471.0	511.0	174.5	142.5	124.9
C_v	0.65	0.53	0.53	0.95	0.74	0.50	0.44	0.66	0.77	0.55	0.57	0.43

Table 22. Statistical analysis summary of monthly and seasonal precipitation, 1914 to 1930 versus 1967 to 1976, Wetaskiwin (α = 5%).

	MONTHLY PRECIPITATION											
	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
F-test	1.95	6.71	1.37	1.37	1.38	3.74	1.31	1.51	4.37	2.14	1.52	5.91
	N.S.	S	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	S
t-test	0.76	0.89[a]	0.31	0.84	1.11	1.81	1.41	0.11	0.87	0.55	0.22	0.00[a]
	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Rank test	69.5	71.0	71.5	56.0	55.0	67.0	66.0	68.0	69.0	71.0	71.5	70.5
	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

	SEASONAL PRECIPITATION	
	WINTER (1 NOV. to 28 FEB.)	NON-WINTER (1 MAR. to 31 OCT.)
F-test	4.37	1.84
	S	N.S.
t-test	0.30[a]	0.63
	N.S.	N.S.

[a] signifies d-test

Table 23. Mean, variance, and coefficient of variation for monthly precipitation (mm), Battleford.

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
	1914 to 1976											
$\bar{x}$	18.0	10.9	15.0	20.6	37.6	59.2	61.7	42.7	31.0	21.1	10.7	13.7
s^2	124.9	54.3	119.3	298.3	423.3	1672.3	1057.0	853.2	671.2	264.3	108.5	62.0
C_v	0.62	0.67	0.73	0.84	0.55	0.69	0.53	0.68	0.84	0.77	0.98	0.57
	1914 to 1930											
$\bar{x}$	15.2	10.7	11.4	23.1	39.6	59.9	49.8	48.8	36.1	21.1	8.9	9.9
s^2	119.3	70.3	79.0	392.5	582.3	1756.4	1040.6	1057.0	780.6	248.0	70.3	43.6
C_v	0.72	0.79	0.78	0.86	0.61	0.70	0.65	0.67	0.77	0.75	0.94	0.67
	1967 to 1976											
$\bar{x}$	22.9	11.2	21.3	16.5	34.0	57.9	81.8	32.5	22.1	21.1	13.7	20.6
s^2	103.2	31.2	124.9	130.6	161.3	1735.2	488.3	402.6	402.6	307.2	167.8	20.9
C_v	0.44	0.50	0.52	0.69	0.37	0.72	0.27	0.62	0.91	0.83	0.94	0.22

Table 24. Statistical analysis summary of monthly and seasonal precipitation, 1914 to 1930 versus 1967 to 1976, Battleford (α = 5%).

	MONTHLY PRECIPITATION											
	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
F-test	1.15	2.27	1.55	3.10	3.63	1.01	2.15	2.60	1.95	1.24	2.55	2.07
	N.S.	N.S.	N.S.	S	S	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
t-test	0.76	0.77	2.48	1.12[a]	0.80[a]	0.13	2.76	1.44	1.36	0.26	1.24	4.47
	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	S
Rank test	105.5	125.0	93.0	114.0	137.0	136.0	92.5	115.5	111.0	139.0	121.0	74.5
	N.S.	N.S.	S	N.S.	N.S.	S	N.S.	S	N.S.	N.S.	N.S.	S

	SEASONAL PRECIPITATION	
	WINTER (1 NOV. to 28 FEB.)	NON-WINTER (1 MAR. to 31 OCT.)
F-test	2.47	5.41
	N.S.	S
t-test	4.57	0.10
	S	N.S.

[a] indicates d-test

during the recent winter period. Precipitation variability in April and May has decreased significantly from the early to the later period with some general tendency for the variances of monthly precipitation to have decreased over time. This is especially evident during the non-winter period. Finally, from the rank test, it would appear that there is a tendency for March, July, and December precipitation values to be higher than in the 1914 to 1930 period.

4.2.2 Daily Precipitation

To investigate the relationship between streamflow changes and short-term precipitation changes, daily precipitation records were examined for the 1914 to 1930 and 1967 to 1976 periods. As there was no significant difference from the early to the later period in snowmelt run off volumes as indicated by unchanged April flows, only the May to September precipitation records were analyzed. Therefore, changes in runoff volumes may be partly explained by changes in summer storm activity as represented by the following parameters: (1) the number of storms per month; (2) storm duration; (3) storm intensity; and (4) maximum one-day, two-day, three-day and four-day precipitation in each month. In this context, 'storm' was defined as any measurable precipitation. The results of this analysis are summarized in Tables 25 to 36.

The analysis of daily precipitation for both Lacombe and Wetaskiwin illustrates that there is a general trend for storm frequency to have increased in more recent times although this trend is not statistically significant for any month. The variability in storm frequency also shows some tendency to have increased at both stations,

Table 25. Mean, variance, and coefficient of variation for storm frequency, duration, and intensity, Lacombe.[a]

Period		MAY			JUNE			JULY		
		Frequency	Duration (days)	Intensity (mm/day)	Frequency	Duration (days)	Intensity (mm/day)	Frequency	Duration (days)	Intensity (mm/day)
1914-30:	$\bar{x}$	5.76	1.59	5.6	5.71	2.31	5.1	5.59	2.16	5.8
	s^2	3.69	0.08	8.4	1.10	1.01	5.6	2.76	0.98	4.2
	C_v	0.33	0.18	0.52	0.18	0.43	0.47	0.30	0.46	0.36
1967-76:	$\bar{x}$	5.30	1.83	3.5	6.30	2.33	6.6	5.90	2.33	5.8
	s^2	4.01	0.40	1.5	1.34	0.51	10.0	3.43	1.40	6.6
	C_v	0.38	0.34	0.34	0.18	0.31	0.48	0.31	0.51	0.45

Period		AUGUST			SEPTEMBER		
		Frequency	Duration (days)	Intensity (mm/day)	Frequency	Duration (days)	Intensity (mm/day)
1914-30:	$\bar{x}$	5.71	1.78	6.1	4.24	1.89	6.5
	s^2	5.10	0.37	5.5	1.57	0.43	17.1
	C_v	0.40	0.34	0.39	0.29	0.35	0.63
1967-76:	$\bar{x}$	6.00	1.94	5.2	5.10	1.96	2.9
	s^2	1.33	0.36	7.0	2.77	0.63	3.1
	C_v	0.19	0.31	0.52	0.33	0.40	0.59

[a] Values are calculated from daily data.

Table 26. Statistical analysis summary of May to September daily precipitation, 1914-1930 and 1967-1976 Lacombe (α = 5%).

	MAY			JUNE			JULY		
	Frequency	Duration (days)	Intensity (mm/day)	Frequency	Duration (days)	Intensity (mm/day)	Frequency	Duration (days)	Intensity (mm/day)
F-test	1.09	5.00	5.60	1.22	1.98	1.79	1.24	1.43	1.79
	N.S.	S	S	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
t-test	0.59	1.08[b]	2.52[b]	1.36	0.06	1.40	0.45	0.40	0.00
	N.S.	N.S.	S	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

	AUGUST			SEPTEMBER		
	Frequency	Duration (days)	Intensity (mm/day)	Frequency	Duration (days)	Intensity
F-test	3.83	1.03	1.27	1.76	1.47	5.52
	S	N.S.	N.S.	N.S.	N.S.	S
t-test	0.45[b]	0.66	0.92	1.53	0.25	2.99[b]
	N.S.	N.S.	N.S.	N.S.	N.S.	S

[a] Values are calculated from daily data.

[b] Indicates 'd-test'.

Table 27. Mean, variance, and coefficient of variation for storm frequency, duration, and intensity, Wetaskiwin.

Period		MAY			JUNE			JULY		
		Frequency	Duration (days)	Intensity (mm/day)	Frequency	Duration (days)	Intensity (mm/day)	Frequency	Duration (days)	Intensity (mm/day)
1914-30:	$\bar{x}$	3.80	1.27	5.2	4.73	1.25	5.7	4.33	1.50	7.9
	s^2	4.74	0.40	11.2	8.21	0.53	15.3	3.95	0.50	34.4
	C_v	0.57	0.50	0.30	0.61	0.58	0.68	0.46	0.47	0.75
1967-76:	$\bar{x}$	3.78	1.63	3.1	5.33	1.96	7.7	5.67	1.90	6.3
	s^2	3.94	0.58	3.0	4.75	0.74	29.4	7.25	0.97	11.7
	C_v	0.53	0.47	0.55	0.41	0.44	0.70	0.47	0.52	0.54

Period		AUGUST			SEPTEMBER		
		Frequency	Duration (days)	Intensity (mm/day)	Frequency	Duration (days)	Intensity (mm/day)
1914-30:	$\bar{x}$	4.87	1.52	5.8	3.27	1.47	8.1
	s^2	3.98	0.45	14.8	3.50	0.67	75.4
	C_v	0.41	0.44	0.66	0.57	0.56	1.07
1967-76:	$\bar{x}$	5.11	1.63	4.6	4.33	1.83	2.8
	s^2	9.61	0.84	9.5	7.00	1.23	3.4
	C_v	0.61	0.56	0.67	0.61	0.61	0.64

Table 28. Statistical analysis summary of May to September daily precipitation, 1914-1930 and 1967-1976, Wetaskiwin (α = 5%).

	MAY			JUNE			JULY		
	Frequency	Duration (days)	Intensity (mm/day)	Frequency	Duration (days)	Intensity (mm/day)	Frequency	Duration (days)	Intensity (mm/day)
F-test	1.20	1.45	3.73	1.73	1.40	1.92	1.84	1.94	2.94
	N.S.	N.S.	S	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
t-test	0.02	1.17	2.16[b]	0.50	1.99	0.96	1.34	1.11	0.70
	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

	AUGUST			SEPTEMBER		
	Frequency	Duration (days)	Intensity (mm/day)	Frequency	Duration (days)	Intensity (mm/day)
F-test	2.41	1.87	1.56	2.00	1.84	26.93
	N.S.	N.S.	N.S.	N.S.	N.S.	S
t-test	0.22	0.32	0.75	1.10	0.87	2.35[b]
	N.S.	N.S.	N.S.	N.S.	N.S.	S

[a] Values are calculated from daily data.

[b] Indicates 'd-test'.

Table 29. Mean, variance, and coefficient of variation for maximum average daily precipitation rate (mm/day), Lacombe.

		MAX. ONE-DAY PRECIP. RATE					MAX. TWO-DAY PRECIP. RATE				
		MAY	JUNE	JULY	AUG.	SEPT.	MAY	JUNE	JULY	AUG.	SEPT.
1914-30	$\bar{x}$	19.0	19.7	20.3	21.4	19.3	12.4	12.5	12.4	12.6	13.1
	s^2	161.7	144.4	141.0	182.8	150.8	75.4	52.1	40.8	56.4	64.7
	C_v	0.67	0.61	0.59	0.63	0.64	0.70	0.58	0.52	0.60	0.61
1967-76	$\bar{x}$	12.2	26.5	26.4	22.9	12.8	7.2	18.2	15.3	15.4	8.6
	s^2	39.2	324.2	204.4	408.4	108.2	13.5	161.0	66.0	132.1	58.4
	C_v	0.52	0.68	0.54	0.88	0.81	0.51	0.70	0.53	0.75	0.87

Table 30. Statistical analysis summary of maximum average daily precipitation rate (mm/day), Lacombe (α = 5%).

		MAX. ONE-DAY PRECIP. RATE					MAX. TWO-DAY PRECIP. RATE				
		MAY	JUNE	JULY	AUG.	SEPT.	MAY	JUNE	JULY	AUG.	SEPT.
1914-1930 vs. 1967-1976	F-test	4.13	2.25	1.45	2.23	1.39	5.59	3.09	1.62	2.43	1.11
		S	N.S.	N.S.	N.S.	N.S.	S	S	N.S.	N.S.	N.S.
1914-1930 vs. 1967-1976	t-test	1.88[a]	1.18	1.20	0.23	1.40	2.11[a]	1.35[a]	1.03	0.77	1.43
		N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

[a] Indicates 'd-test'.

Table 31. Mean, variance, and coefficient of variation for maximum average daily precipitation rate (mm/day), Lacombe.

		MAX. THREE-DAY PRECIP. RATE					MAX. FOUR-DAY PRECIP. RATE				
		MAY	JUNE	JULY	AUG.	SEPT.	MAY	JUNE	JULY	AUG.	SEPT.
1914-30	$\bar{x}$	8.9	9.1	10.5	9.3	9.7	7.5	7.4	8.4	8.1	8.0
	s^2	34.6	27.7	38.3	37.3	36.5	21.8	18.4	21.5	25.1	25.3
	C_v	0.66	0.58	0.59	0.66	0.62	0.63	0.58	0.55	0.62	0.63
1967-76	$\bar{x}$	5.5	13.0	12.2	11.2	6.0	4.4	10.6	10.1	8.7	4.7
	s^2	8.9	70.4	42.8	63.3	26.2	6.1	41.9	23.3	37.8	14.7
	C_v	0.55	0.65	0.53	0.71	0.85	0.57	0.61	0.48	0.71	0.81

Table 32. Statistical analysis summary of maximum average daily precipitation rate (mm/day), Lacombe (α = 5%).

		MAX. THREE-DAY PRECIP. RATE					MAX. FOUR-DAY PRECIP. RATE				
		MAY	JUNE	JULY	AUG.	SEPT.	MAY	JUNE	JULY	AUG.	SEPT.
1914-1930 vs. 1967-1976	F-test	3.89	2.54	1.12	1.70	1.39	3.57	2.28	1.08	1.51	1.72
		S	N.S.	N.S.	N.S.	N.S.	S	N.S.	N.S.	N.S.	N.S.
1914-1930 vs. 1967-1976	t-test	2.01[a]	1.49	0.68	0.70	1.62	2.28[a]	1.55	0.91	0.28	1.79
		N.S.	N.S.	N.S.	N.S.	N.S.	S	N.S.	N.S.	N.S.	N.S.

[a] Indicate 'd-test'.

Table 33. Mean, variance, and coefficient of variation for maximum average daily precipitation rate (mm/day), Wetaskiwin.

		MAX. ONE-DAY PRECIP. RATE					MAX. TWO-DAY PRECIP. RATE				
		MAY	JUNE	JULY	AUG.	SEPT.	MAY	JUNE	JULY	AUG.	SEPT.
1914-30	$\bar{x}$	13.2	17.5	19.6	16.5	16.9	9.4	11.3	11.4	11.9	10.0
	s^2	30.0	43.3	138.7	96.4	127.8	31.9	16.7	51.2	33.4	41.3
	C_v	0.42	0.38	0.60	0.59	0.67	0.60	0.36	0.63	0.49	0.64
1967-76	$\bar{x}$	11.3	36.1	30.4	17.3	10.2	7.2	27.3	18.0	12.6	7.3
	s^2	36.5	651.3	433.9	85.2	55.3	29.1	371.1	108.5	76.4	33.5
	C_v	0.53	0.71	0.68	0.53	0.73	0.75	0.71	0.58	0.69	0.79

Table 34. Statistical analysis summary of maximum average daily precipitation rate (mm/day), Wetaskiwin (α = 5%).

		MAX. ONE-DAY PRECIP. RATE					MAX. TWO-DAY PRECIP. RATE				
		MAY	JUNE	JULY	AUG.	SEPT.	MAY	JUNE	JULY	AUG.	SEPT.
1914-1930 vs. 1967-1976	F-test	1.22	15.04	3.13	1.13	2.31	1.10	22.22	2.12	2.29	1.23
		N.S.	S	S	N.S.	N.S.	N.S.	S	N.S.	N.S.	N.S.
1914-1930 vs. 1967-1976	t-test	0.74	2.15[a]	1.57[a]	0.19	1.49	0.88	2.46[a]	1.76	0.23	0.98
		N.S.	S	N.S.	N.S.	N.S.	N.S.	S	N.S.	N.S.	N.S.

[a] Indicates 'd-test'.

Table 35. Mean, variance, and coefficient of variation for maximum average daily precipitation rate (mm/day), Wetaskiwin.

		MAX. THREE-DAY PRECIP. RATE					MAX. FOUR-DAY PRECIP. RATE				
		MAY	JUNE	JULY	AUG.	SEPT.	MAY	JUNE	JULY	AUG.	SEPT.
1914-30	$\bar{x}$	6.9	8.0	8.1	8.8	7.3	5.5	6.7	7.2	7.2	5.6
	s^2	22.7	8.9	23.4	23.9	25.3	14.4	7.3	21.1	20.2	14.8
	C_v	0.70	0.38	0.59	0.56	0.68	0.69	0.40	0.64	0.63	0.68
1967-76	$\bar{x}$	5.1	20.0	16.2	10.3	5.3	4.2	16.0	12.8	8.2	4.2
	s^2	15.9	178.9	72.3	40.7	16.6	12.8	117.3	46.0	29.4	9.4
	C_v	0.78	0.67	0.52	0.62	0.77	0.86	0.68	0.53	0.66	0.74

Table 36. Statistical analysis summary of maximum average daily precipitation rate (mm/day), Wetaskiwin (α = 5%).

		MAX. THREE-DAY PRECIP. RATE					MAX. FOUR-DAY PRECIP. RATE				
		MAY	JUNE	JULY	AUG.	SEPT.	MAY	JUNE	JULY	AUG.	SEPT.
1914-1930 vs. 1967-1976	F-test	1.43	20.10	3.09	1.70	1.52	1.13	16.07	2.18	1.46	1.57
		N.S.	S	S	N.S.	N.S.	N.S.	S	N.S.	N.S.	N.S.
1914-1930 vs. 1967-1976	t-test	0.89	2.65[a]	2.87[a]	0.62	0.96	0.78	2.53[a]	2.31	0.47	0.88
		N.S.	S	S	N.S.	N.S.	N.S.	S	S	N.S.	N.S.

[a] Indicates 'd-test'.

although, for the month of August at Lacombe, a statistically significant decrease in variability occurred.

Also, it is apparent that there is a tendency for storms to be slightly longer in more recent times and a trend towards increased variability of storm duration at both stations. However, only May for Lacombe exhibited a significantly higher variance.

From the same tables, it would appear that there is a trend towards decreasing storm intensity for May, July, August, and September, being most pronounced in the months of May and September. June is anomalous as the mean storm intensity has increased slightly at both Lacombe and Wetaskiwin. Finally, there is no apparent trend in the variability of storm intensity, with May and September showing significant decreases at both stations while other months have either increased or decreased to a lesser extent.

The analysis of maximum one-day, two-day, three-day, and four-day precipitation intensity at Lacombe (Tables 29 to 32) shows that there are no clear trends as the means and variances are lower for May and September in the 1967 to 1976 period and higher in June, July, and August.

A similar analysis performed on the precipitation recorded at Wetaskiwin shows the same general trends in both the variances and means (Tables 33 to 36), although statistically, some of the monthly results are different. For example, the mean one-day, two-day, three-day, and four-day precipitation is only slightly higher in the recent period at Lacombe but significantly higher at Wetaskiwin.

4.2.3 Summary of Precipitation Changes

From the preceding analysis of the changes in precipitation characteristics at Lacombe, Wetaskiwin, and Battleford, between the 1914 to 1930 and 1967 to 1976 periods, the following observations can be made:

1. Mean monthly precipitation has not changed significantly at either Lacombe or Wetaskiwin;
2. There are no noticeable trends in the variability of monthly precipitation at Lacombe and Wetaskiwin;
3. A tendency is apparent for precipitation variability at Battleford to have decreased, especially for the non-winter period;
4. A slight trend towards higher precipitation is apparent for the winter period at Battleford;
5. The number of summer storms per month has tended to increase at both Lacombe and Wetaskiwin;
6. There is a tendency for recent summer storms to be slightly longer at both stations;
7. At both Lacombe and Wetaskiwin, storm intensity has tended to decrease for May, July, August, and September, and to increase for June; and
8. For both Lacombe and Wetaskiwin, there are no clear trends in variability and means of maximum one-day, two-day, three-day, and four-day summer precipitation intensities.

4.3 TEMPERATURE REGIME

Longley (1977) has examined climatic change in Alberta using records from a number of stations. The results of his study indicate that, for Lacombe and Wetaskiwin, the 10 year running mean growing season temperature (May to September, inclusive) at both these stations increased slightly to a maximum in the early 1940's from lows recorded in the 1910 to 1920 decade. Growing season temperatures decreased during the 1950's and then increased to the present high levels. Also, Longley (1977) observed that there is a tendency for the summer minimum temperature to increase and that this increase appears to be general for the prairies. This indicates that there is a corresponding rise in the length of the frost-free period. However, there is a corresponding decrease in the 10 year running mean maximum growing season temperature such that there is no clearly discernible change in the mean growing season temperature.

Data for Edmonton (Alberta Environment 1976) indicate that the annual mean temperature appears to have undergone a cooling trend with the annual mean temperature from 1964 to 1975 being approximately 1.7^{o}C below normal. However, it is not clear from this study whether this trend would also apply to summer temperatures and what effect this would have on lake evaporation and consumptive use.

Tables 37 to 40 indicate that in general the mean monthly temperature during the growing season has increased from the early period to the later period at both Lacombe and Wetaskiwin. These results are in agreement with Longley (1977). However, none of these results are statistically significant. The variability of mean monthly

Table 37. Statistics of growing degree-days above 5°C, 1914 to 1930 and 1967 to 1976, Lacombe.

	1914 to 1930 Period				
	MAY	JUNE	JULY	AUGUST	SEPTEMBER
No. of Years	17	17	17	17	17
$\bar{x}$	126.6	234.6	339.2	295.9	144.0
s^2	1410.6	1067.6	738.6	1388.4	1239.5
C_v	0.30	0.14	0.08	0.13	0.24

	1967 to 1976 Period				
	MAY	JUNE	JULY	AUGUST	SEPTEMBER
No. of Years	10	10	10	10	10
$\bar{x}$	148.0	250.4	322.7	307.1	153.5
s^2	1421.7	1840.5	1334.8	3566.5	3533.6
C_v	0.25	0.17	0.11	0.19	0.37

Table 38. Statistical analysis summary of growing degree-days above 5°C, 1914 to 1930 and 1967 to 1976, Lacombe (α = 5%).

	MAY	JUNE	JULY	AUGUST	SEPTEMBER
F-test	1.01	1.72	1.81	2.57	2.60
	N.S.	N.S.	N.S.	N.S.	N.S.
t-test	1.43	1.09	1.35	0.60	0.54
	N.S.	N.S.	N.S.	N.S.	N.S.

Table 39. Statistics of growing degree-days above 5°C, 1914 to 1930 and 1967 to 1976, Wetaskiwin.

	1914 to 1930 Period				
	MAY	JUNE	JULY	AUGUST	SEPTEMBER
No. of Years	13	12	14	14	14
$\bar{x}$	140.3	246.8	342.9	280.8	142.1
s^2	1050.2	1230.2	439.3	1572.1	1034.9
C_v	0.23	0.14	0.06	0.14	0.23

	1967 to 1976 Period				
	MAY	JUNE	JULY	AUGUST	SEPTEMBER
No. of Years	8	8	8	8	8
$\bar{x}$	166.0	285.8	336.9	333.8	157.2
s^2	1366.5	1648.1	783.5	3312.0	3601.2
C_v	0.22	0.14	0.08	0.17	0.38

Table 40. Statistical analysis summary of growing degree-days above 5°C, 1914 to 1930 and 1967 to 1976, Wetaskiwin (α = 5%).

	MAY	JUNE	JULY	AUGUST	SEPTEMBER
F-test	1.30	1.34	1.78	2.11	3.48
	N.S.	N.S.	N.S.	N.S.	N.S.
t-test	1.68	2.29	0.57	2.56	0.78
	N.S.	N.S.	N.S.	N.S.	N.S.

temperature during the May to September period has also tended to increase but only the September variance at Wetaskiwin is statistically significant.

Table 41 indicates that the mean annual growing season temperature has increased from the 1920 to 1930 period to the 1967 to 1974 period at both Lacombe and Wetaskiwin with the difference being statistically significant for the latter station only. These results indicate that the location of the climate stations may affect the results of an analysis and may make their physical interpretation more difficult. However, since it is not known which of these two stations would be more representative of the headwater area of the Battle River Basin, the only conclusion from this analysis is that growing-season temperature has increased over time. This is true for the variability of annual growing-season temperature as well.

Table 41. Statistics of mean annual growing season degree-days above 5°C, Lacombe and Wetaskiwin (α = 5%).

	LACOMBE				WETASKIWIN	
Period	1914-30	1967-76	1920-30	1967-74	1920-30	1967-74
$\bar{x}$	1140.5	1181.8	1150.8	1186.1	1136.9	1279.7
s^2	5365.4	13,825.4	5431.7	16,412.5	6348.0	12,127.6
F-test	2.58		3.02		1.91	
	S		N.S.		N.S.	
t-test	1.00[a]		0.76		3.29	
	N.S.		N.S.		S	

[a] Indicates 'd-test'.

5. ANALYSIS OF STREAMFLOW AND LAKE LEVEL CHANGES

5.1 INTRODUCTION

From the previous sections, it has been demonstrated that the flow regime of the Battle River near Ponoka has not been consistent over the period of record and that some study lakes have exhibited variations in level over time. It has also been shown that in general the climate has not changed significantly for the Battle River Basin, although changes in certain climatic variables have been observed. Therefore, it is likely that changes in runoff and lake levels can only be explained by a combination of changes in climate and changing land use.

The effect that deforestation has on the runoff process is not well understood, especially in plains regions with low annual precipitation. In mountainous areas with high snowfall amounts, increased yields are common in deforested areas with most of this increase occurring in the surface runoff component of the snowmelt period (Neill 1980). The lack of forest cover reduces interception loss and increases snow accumulation, snow density, and snowmelt rates (Johnson et al. 1971). In mountainous regions where precipitation is mainly rain, deforestation increases water yields by reducing water consumption by vegetation (Oldman River Basin Study management Committee 1977). However, as will be seen in this section, from studies done in southern Alberta (Laycock 1973; Alberta Environment 1976; Oldman River Basin Study Management Committee 1977; Neill 1980), evidence suggests that in prairie regions, deforestation may not increase total basin yield.

In the case of the Battle River Basin upstream from Ponoka, total annual runoff has decreased significantly. Figure 3 illustrates graphically that overland flow has decreased substantially since the early period. This is evident from the reduced hydrograph response in the summer months for the more recent period compared to the earlier period. Groundwater flows have also decreased as shown by the significantly lower winter flows for the Battle River near Ponoka (see Table 4) in the 1967 to 1976 period. If the observed changes in streamflow and lake levels cannot be explained by variations in precipitation characteristics, then any increase in available moisture due to a reduction in overland flow must not have percolated to the groundwater table but instead must have been utilized in increased consumptive use and/or increased evaporation from the soil surface. These hypotheses are examined in this section to formulate an explanation for the observed changes in Battle River flows above Ponoka and the major variations in levels for the lakes of central Alberta.

5.2 ANALYSIS OF STREAMFLOW CHANGES

5.2.1 Introduction

From Section 2, it was concluded that the mean monthly flows of the Battle River near Ponoka have decreased significantly in every month except April and September, while the variances have decreased significantly in all months except April and August. The mean flow in April has increased slightly, while September flows have decreased. The observation that April flows have not significantly changed is extremely important as this month accounts for a very large proportion of the mean

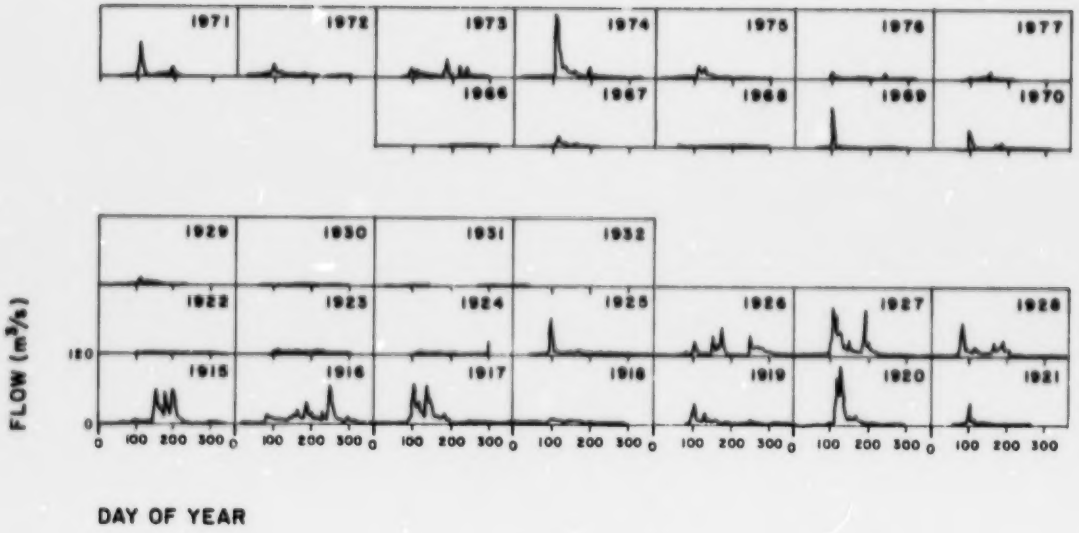

Figure 3. Annual streamflow hydrographs for the Battle River Basin near Ponoka, 1915 to 1932 and 1966 to 1977.

annual Battle River flows (22% for the 1914 to 1930 period and 48% for the 1967 to 1976 period).

The changes in mean monthly flows at Battleford are very different from those observed near Ponoka (Table 42). March flows have increased significantly in the later period while November flows are significantly lower. Also, the variances have decreased for the late summer and winter months and increased for the spring months.

It is evident that major changes in the flow regime in the headwater drainage area have occurred during both winter and summer. The major difference between the records at Battleford and Ponoka is that flows have tended to increase slightly at Battleford while decreasing significantly at Ponoka. To understand why the regime has changed during the winter required an examination of factors such as groundwater levels, changing land use, and the carry-over effects of non-winter precipitation. Changes in May and June may be related to a combination of winter and non-winter precipitation as well as to the effects of changing land use patterns. Finally, differences in July and August may be explained by examination of precipitation and land use changes.

Table 42. Summary of streamflow changes for the Battle River near Ponoka, Alberta, and at Battleford, Saskatchewan with respect to the early period of record.

	Ponoka[a]			Battleford[a]		
	$\bar{x}$	s^2	C_v	$\bar{x}$	s^2	C_v
Jan.	L*	L†	L	L	L†	L
Feb.	L*+	L†	L	N	L	L
March	L+	L†	L	H+	H†	H
April	H	L	L	H	H	L
May	L+	L†	L	H	H†	H
June	L*+	L†	L	H	H	H
July	L+	L†	L	L	L	L
Aug.	L+	L	H	L	L†	L
Sept.	L	L†	L	L	L†	L
Oct.	L*+	L†	L	L	L†	L
Nov.	L*	L†	L	L*	L†	L
Dec.	L*	L†	L	N	L	L

[a] H = higher
L = lower
N = no change
* = statistically significant (t-test or d-test)
+ = statistically significant (Rank Test)
† = statistically significant (F-test)

5.2.2 Precipitation-Runoff Relationships

The analysis of the monthly precipitation regime at Lacombe, Wetaskiwin, and Battleford has indicated that certain months exhibited differences in means and/or variances between the 1914 to 1930 and 1967 to 1976 periods (Table 43). Statistically, however, none of the mean precipitation values are significantly different at either Lacombe or Wetaskiwin. Since the winter precipitation has not changed, there is no reason to expect streamflow values to have varied in the peak snowmelt month of April. This is confirmed by the records for the Battle River. Similarly, the fact that the mean monthly non-winter precipitation has not changed significantly at any of the three stations implies that the changes in flow regime of the Battle River above Ponoka from the 1914 to 1930 period to the 1967 to 1976 period cannot be explained in terms of physical changes in monthly precipitation amounts. In fact, June precipitation at both Lacombe and Wetaskiwin has increased slightly while flows have decreased significantly. Either other physical factors must be operative within the Battle River Basin to produce the observed flow regime changes or streamflow may be responding to precipitation changes on a time basis less than 1 mo in duration.

From examination of daily precipitation records for Lacombe and Wetaskiwin (Tables 44 and 45), it is evident that there were significant differences in some of the parameters analyzed. For May, the mean frequency of storms and maximum one-day, two-day, three-day, and four-day precipitation amounts have decreased while the length of storms has tended to increase. At the same time storm intensity has decreased significantly. The effect of these changes should be to

Table 43. Summary of monthly precipitation changes for Lacombe, Wetaskiwin, and Battleford with respect to the early period of record.

	Lacombe[a]			Wetaskiwin[a]			Battleford[a]		
	$\bar{x}$	s^2	C_v	$\bar{x}$	s^2	C_v	$\bar{x}$	s^2	C_v
Jan.	H	H↑	H	H	H	H	H	L	L
Feb.	L	L	N	L	L↑	L	N	L	L
March	L	L	L	H	H	N	H+	H↑	L
April	L	L	H	L	L	H	L	L↑	L
May	L	L	H	L	L	H	L	L↑	L
June	H	L	L	H	H	H	L	N	N
July	H	H	N	H	H	L	H+	L	L
Aug.	N	H	H	N	H	H	L	L	L
Sept.	L	L	H	L	L	L	L	L	H
Oct.	H	H	N	H	L	L	N	H	H
Nov.	L	L	L	N	L	L	H	H	N
Dec.	H	L↑	L	N	L	L↑	H*+	L	L

[a] H = higher
L = lower
N = no change
* = statistically significant (t-test)
+ = statistically significant (Rank Test)
↑ = statistically significant (F-test)

Table 44. Summary of changes in storm characteristics for Lacombe and Wetaskiwin with respect to the early period of record.

		Frequency[a]			Duration[a] (#days/storm)			Intensity[a] (mm/day)		
		$\bar{x}$	s^2	C_v	$\bar{x}$	s^2	C_v	$\bar{x}$	s^2	C_v
LACOMBE	May	L	H	H	H	H†	H	L*	L†	L
	June	H	H	N	N	L	L	H	H	N
	July	H	L	N	H	H	H	N	H	H
	Aug.	H	L†	L	H	N	N	L	H	H
	Sept.	H	H	N	N	H	N	L*	L†	N
WETASKIWIN	May	N	L	N	H	H	N	L	L†	H
	June	H	L	L	H	H	L	H	H	N
	July	H	H	N	H	H	N	L	L	L
	Aug.	H	H	H	H	H	H	L	L	N
	Sept.	H	H	N	H	H	N	L*	L†	L

[a] H = higher
L = lower
N = no change
* = statistically significant (t-test or d-test)
† = statistically significant (F-test)

Table 45. Summary of changes in maximum precipitation for Lacombe and Wetaskiwin with respect to the early period of record.

		MAX. ONE-DAY[a]			MAX. TWO-DAY[a]			MAX. THREE-DAY[a]			MAX. FOUR-DAY[a]		
		$\bar{x}$	s^2	C_v	$\bar{x}$	s^2	C_v	$\bar{x}$	s^2	C_v	$\bar{x}$	s^2	C_v
LACOMBE	May	L	L†	L	L	L†	L	L	L†	L	L*	L†	L
	June	H	H	H	H	H†	H	H	H	H	H	H	N
	July	H	H	L	H	H	N	H	H	L	H	H	L
	Aug.	H	H	H	H	H	H	H	H	H	H	H	H
	Sept.	L	L	H	L	L	H	L	L	H	L	L	H
WETASKIWIN	May	L	H	H	L	L	H	L	L	H	L	L	H
	June	H*	H†	H	H*	H†	H	H*	H†	H	H*	H†	H
	July	H	H†	H	H	H	L	H*	H†	L	H*	H†	L
	Aug.	H	L	L	H	H	H	H	H	H	H	H	H
	Sept.	L	L	H	L	L	H	L	L	H	L	L	H

[a] H = higher
L = lower
N = no change
* = statistically significant (t-test or d-test)
† = statistically signfiicant (F-test)

generate less surface runoff and to reduce streamflow for the Battle River above Ponoka. This is indicated in the streamflow records and suggests that at least for the month of May, streamflow is partly responding to the precipitation regime.

For the month of June, storms have tended to become more frequent, of longer duration, and of greater intensity. The maximum daily precipitation lasting 1, 2, 3, and 4 d has also tended to increase. These changes should produce an increase in overland flow which should enhance the flows of the Battle River above Ponoka for this month. From the streamflow records, however, it is evident that the reverse has happened: mean flows of the Battle River near Ponoka for June have very definitely decreased. Therefore, there is evidently no clear relationship between precipitation and runoff for the month of June.

For the months of July and August, it is observed that there is a tendency for storm frequency, storm duration, and the maximum one-, two-, three-, and four-day precipitation to have increased in the 1967 to 1976 period. At the same time, mean monthly precipitation intensity has tended to decrease slightly. The net effect that these changes would have on streamflow is not certain but it is doubtful whether the statistically non-significant decrease in storm intensity for these months is sufficient to explain the significantly lower runoff at Ponoka in the more recent period.

Both the frequency and duration of storms have increased and maximum one-, two-, three-, and four-day precipitation have decreased during September at Lacombe and Wetaskiwin. The mean monthly

precipitation intensity has decreased significantly. The net result should be a decrease in flows for the Battle River near Ponoka and such is indeed the case. Thus, September flows appear to be responding to the effects of precipitation changes.

From the preceding analysis of monthly and daily precipitation as recorded at Lacombe and Wetaskiwin, the following relationships between streamflow on the Battle River near Ponoka and precipitation may be stated:

1. Streamflow has not changed significantly from the 1914 to 1930 period to the 1967 to 1976 period in the month of April and this observation is consistent with the fact that winter precipitation has also not changed significantly at either Lacombe or Wetaskiwin;
2. Mean monthly non-winter precipitation is not useful in explaining Battle River flows in the headwater area;
3. Lower streamflow values for May would appear to be at least partly related to reduced mean daily precipitation intensity;
4. Precipitation in June favours higher values of streamflow but significantly lower values have been observed;
5. It is doubtful whether the observed changes in precipitation in July and August would sufficiently explain the very significantly reduced flows for these months; and
6. September flows would appear to be responding to decreased precipitation intensity.

In conclusion, therefore, the streamflow regime of the Battle River above Ponoka is related to winter, May, and September precipitation amounts. Streamflow in the months of June, July, and August appears to be unrelated to precipitation. Any interpretation of the streamflow regime for these months must involve other physical factors.

5.2.3. Land Use-Runoff Relationships

From examination of the means and coefficients of variation for the Battle River near Ponoka (Table 4) from November to February inclusive, it is apparent that the over-winter contribution to annual streamflow volumes was relatively constant within each period but that winter streamflows during the 1967 to 1976 period were between 23 and 27% of the 1914 to 1930 winter flows. Since groundwater flow represents the only source of runoff in winter, this suggests that groundwater levels have declined in the Battle River Basin above Ponoka. This conclusion is difficult to verify as groundwater levels have only recently been recorded for parts of the basin. For example, an observation well completed at the north end of Gull Lake in 1965 provides the longest available period of record. From these data (Appendix 8.4, Tables 63 to 66), it can be seen that groundwater levels at this location have declined approximately 0.8 m from 1965 to 1978. Whether this decline is regional or localized in extent is not certain but it is probable that the average groundwater level for the entire Battle River Basin may not have changed significantly. This is inferred from an examination of Table 46 which indicates that the mean unit runoff over winter at Battleford has remained relatively constant for

Table 46. Mean monthly discharge (m^3/s per 1000 km^2), Battle River near Ponoka and at Battleford.

	Ponoka		Battleford	
	1914-1930	1967-1976	1914-1930	1967-1976
January	0.36	0.08	0.04	0.03
February	0.34	0.08	0.03	0.03
March	1.13	0.31	0.03	0.17
April	5.07	5.29	1.06	1.66
May	4.43	1.89	1.03	1.73
June	3.76	0.81	0.67	0.68
July	3.39	1.16	0.49	0.44
August	0.94	0.59	0.37	0.30
September	1.71	0.15	0.27	0.17
October	0.09	0.15	0.23	0.14
November	0.54	0.16	0.24	0.08
December	0.38	0.10	0.04	0.04

the period of record when compared to the upstreamflows. In order for the groundwater discharge at Battleford to have remained stable, groundwater discharge downstream from Ponoka must have increased to compensate for the groundwater decline upstream.

The reasons for declining groundwater levels in the headwater region of the basin are not evident. The decline is certainly not due to increased groundwater pumping rates as this quantity is negligible (see Section 1), and does not appear to be the direct result of decreased precipitation as the precipitation regime has not changed significantly from the 1914 to 1930 period to the present. The lower groundwater levels and reduced streamflow may be related to changing land use patterns.

The upstream portion of the Battle River Basin has experienced deforestation since 1930 (Figure 4), but the effects this land use change may have in modifying runoff patterns is difficult to assess. For example, in mountainous areas, it is commonly accepted that deforestation increases water yields, apparently as a result of less infiltration of precipitation and less evapotranspiration. However, as pointed out by a report prepared for the Oldman River Basin Study Management Commitee in 1977, the relationship between the magnitude and timing of the runoff response to forest cover treatment is extremely complex, varying with precipitation type and amount, soils, elevation, latitude, topography, tree species, and tree density, among other factors. Extrapolation of these results to plains watersheds is even more difficult, partly because very few studies have been done in these environments but also because existing data are related to small

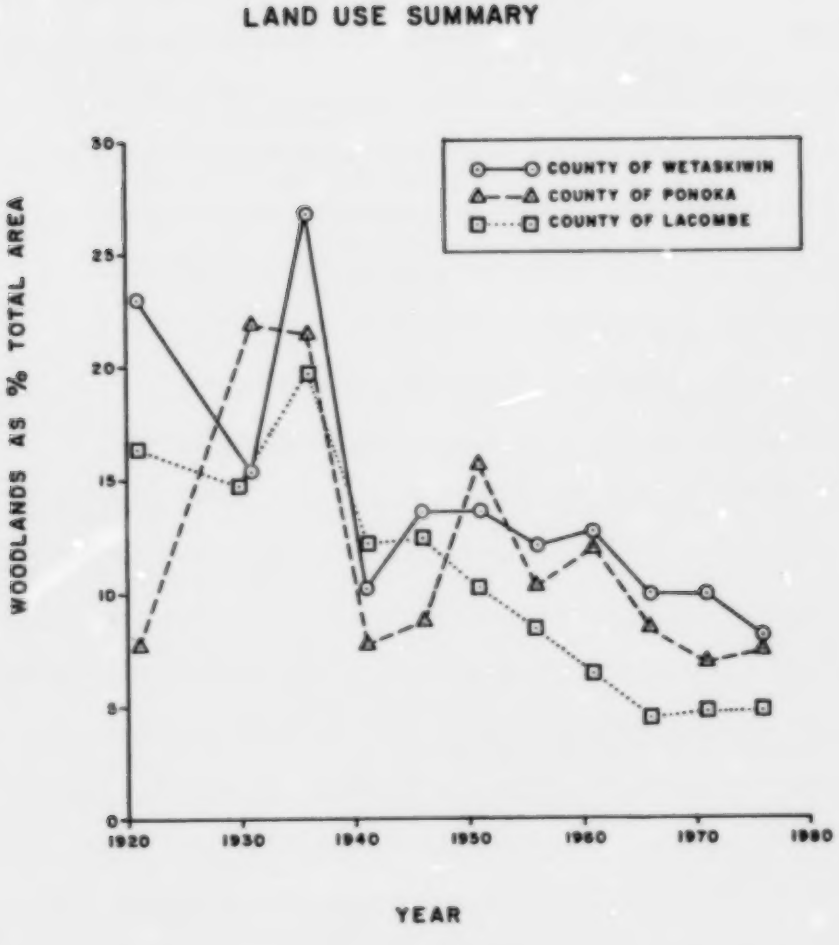

Figure 4. Area of woodlands versus time, Wetaskiwin, Ponoka, and Lacombe counties, 1921 to 1976.

watershed areas. Hibbert (1967) reported that afforestation of grassland gradually decreases water yield but not to the same degree that deforestation increases yield initially. Studies in the Soviet Union indicate that for plains regions, the greater the degree of forestation, the greater the water yield. However, from these studies, it is not clear whether a correlation between streamflow and forest cover indicates cause and effect or whether the relationship simply indicates that forest cover is more likely to persist where precipitation is high and evaporation low.

Neill (1980) investigated manipulation of forest cover as a method of augmenting runoff in southern Alberta. Some of his conclusions are:

1. Results from the Colorado Rockies, where over half the annual precipitation is snow, indicate that increased yields appear almost entirely in the snowmelt period;
2. For large watersheds, where yield is mostly from snowmelt, the effect of trees is to enhance and protect the snowpack. That is, any "negative results of clearing may be due to greater exposure of snow to wind and sun" (1980:63);
3. Results from a three-year study at Marmot Creek watershed did not conclusively show that cutting had increased water yields. Since this study was done during a dry period,the implication is that deforestation may not increase yields in areas of low annual precipitation, such as the prairies;

4. For the upper Oldman River basin "despite extensive fires and logging at various times in the past, there is no convincing evidence of deterministic changes in annual runoff volumes over the historical period" (1980:72);
5. Finally, "it is not clear that significant water yield benefits can be obtained by maintaining cleared areas where chinook winds are prevalent" (1980:66) and "it appears that the significance of chinook conditions in relation to snowmelt, evaporation and runoff merits further scientific investigation" (Neill, 1980:72).

From these conclusions, therefore, it would appear that the primary effect of deforestation would be to increase snowmelt runoff. However, since April flows for the Battle River near Ponoka have not changed significantly, any effects of land clearing on spring runoff are negligible within this basin. This is likely due to the fact that the greatest amount of land clearing occurred before streamflow records were initiated. In the last 50 to 60 years, woodlands in the counties of Lacombe, Ponoka, and Wetaskiwin have decreased, on the average, from 16% of the combined total area in 1921 to 7% of the area in 1976 (Figure 4) and it may be that the relatively low amount of landclearing (approximately 525 ha/year) is not significant enough to appreciably affect snow retention and subsequent snowmelt runoff or summer streamflow. Whether other land use changes can lead to the type of reductions in streamflow during the summer months, observed for the Battle River near Ponoka, should be examined further.

Land use changes in Alberta have been documented since 1921 in Alberta census data (see Appendix 8.3, Tables 60 to 62). The counties of Ponoka, Lacombe, and Wetaskiwin were selected to be representative of the headwater area above Ponoka. Since the county boundaries have changed from one census to the next, it was decided to express the various land use categories as a percent of the total land within each county. This information is illustrated in Figures 4 to 9.

From examination of these graphs, the following trends and changes may be observed:

1. There has been a general increase over time of the area of each county in field crops with a slight decline during the 1930's. The field crop acreage increased from 27% of the combined county area in 1921 to 51% in 1976. Also, there is a tendency for field crop acreage to be higher for the more southerly county (Lacombe), although the rate of increase in field crop acreage is similar for all counties.
2. The percentage of area under fallow generally increased until 1946, and after this census, has tended to decrease, so that present levels are approximately equivalent to 1931 levels.
3. The area of woodland has tended to decrease with time as indicated earlier, but both large and small increases in this category have been experienced from one census to another. It would appear this may be due to differences in interpretation from one census to another, as well as

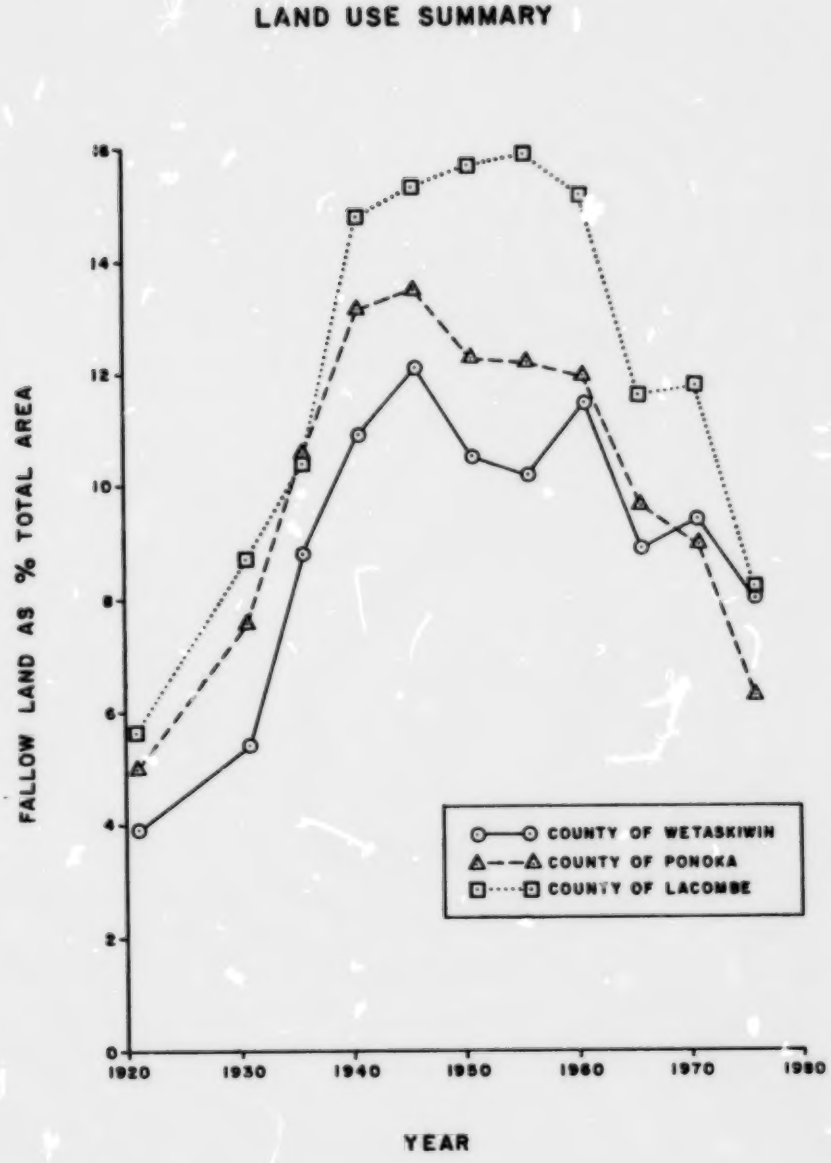

Figure 5. Area of fallow land versus time, Wetaskiwin, Ponoka, and Lacombe counties, 1921 to 1976.

LAND USE SUMMARY

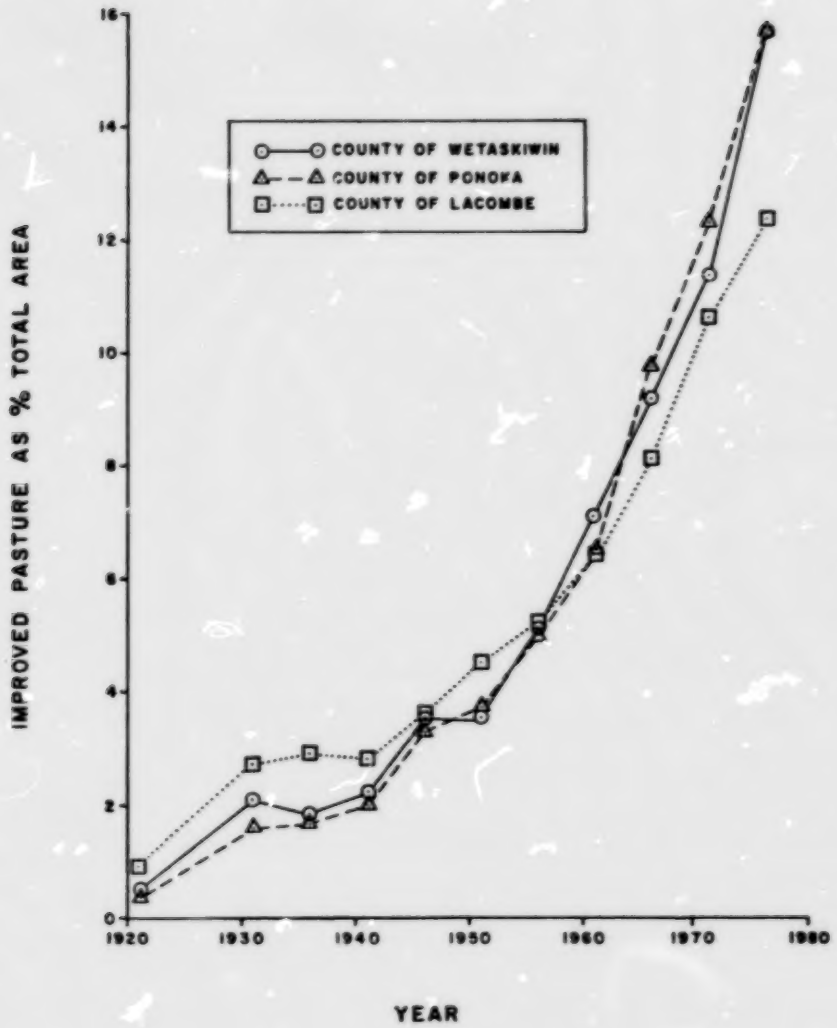

Figure 6. Area of improved pasture versus time, Wetaskiwin, Ponoka, and Lacombe counties, 1921 to 1976.

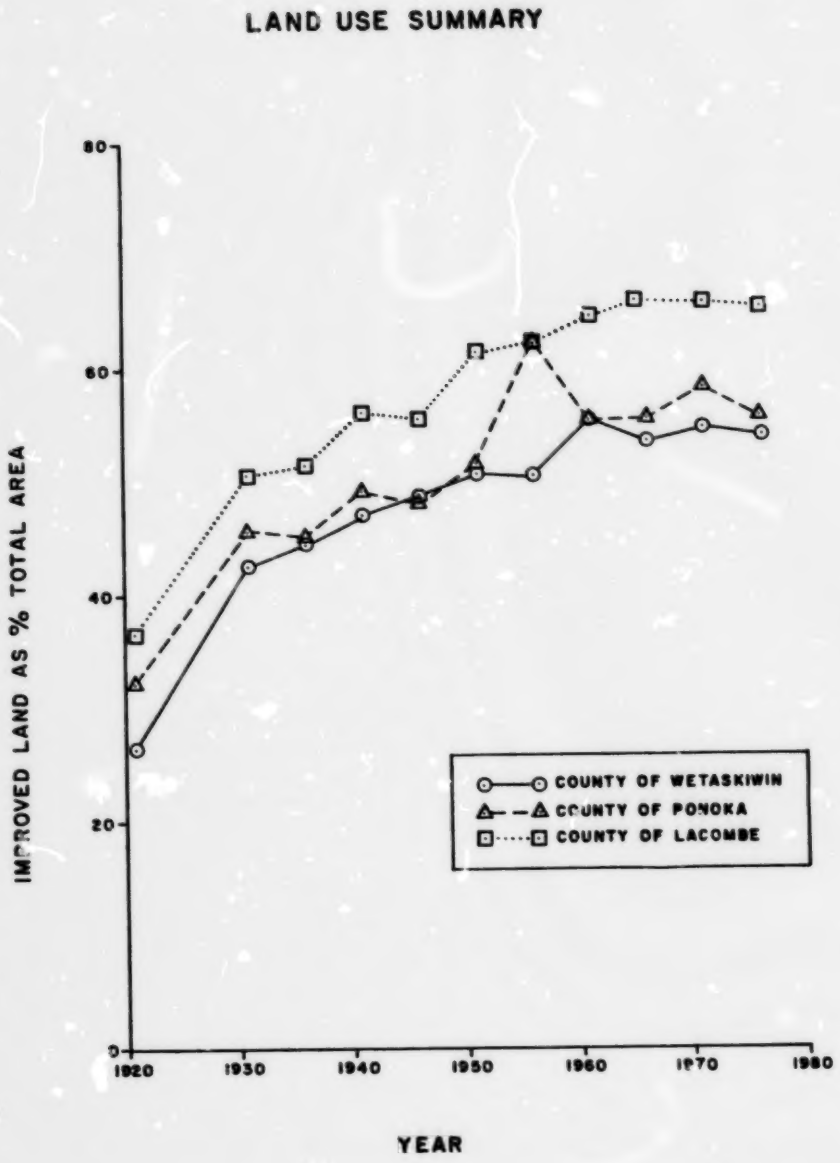

Figure 7. Area of improved land versus time, Wetaskiwin, Ponoka, and Lacombe counties, 1921 to 1976.

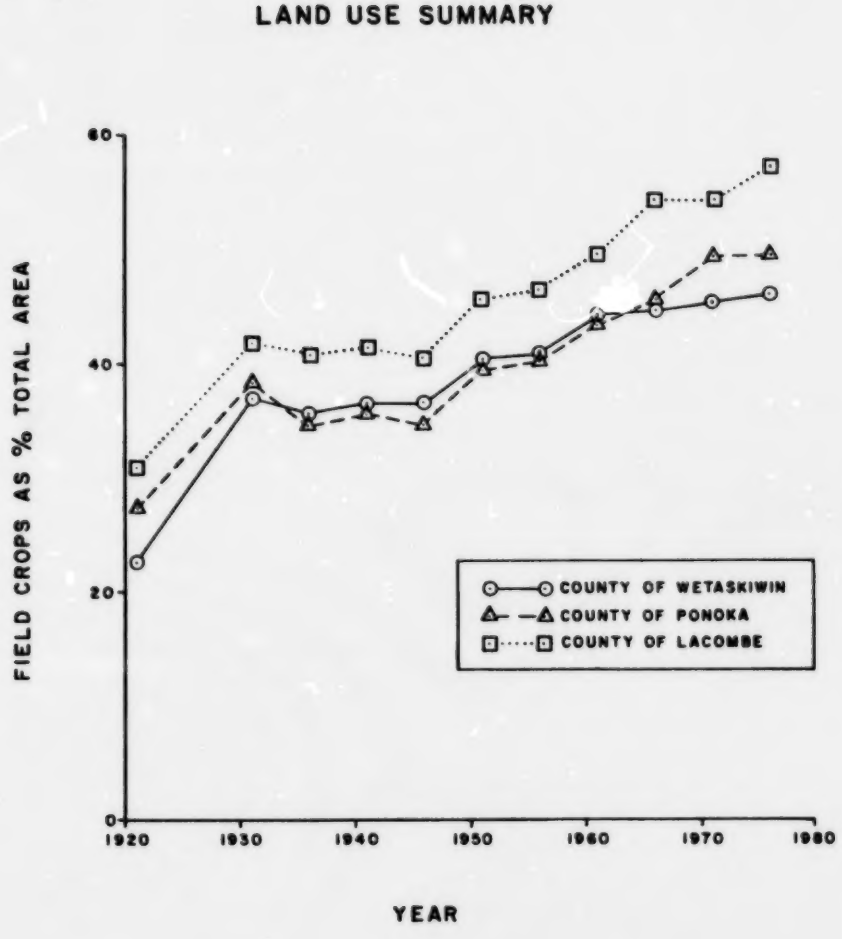

Figure 8. Area of field crops versus time, Wetaskiwin, Ponoka, and Lacombe counties, 1921 to 1976.

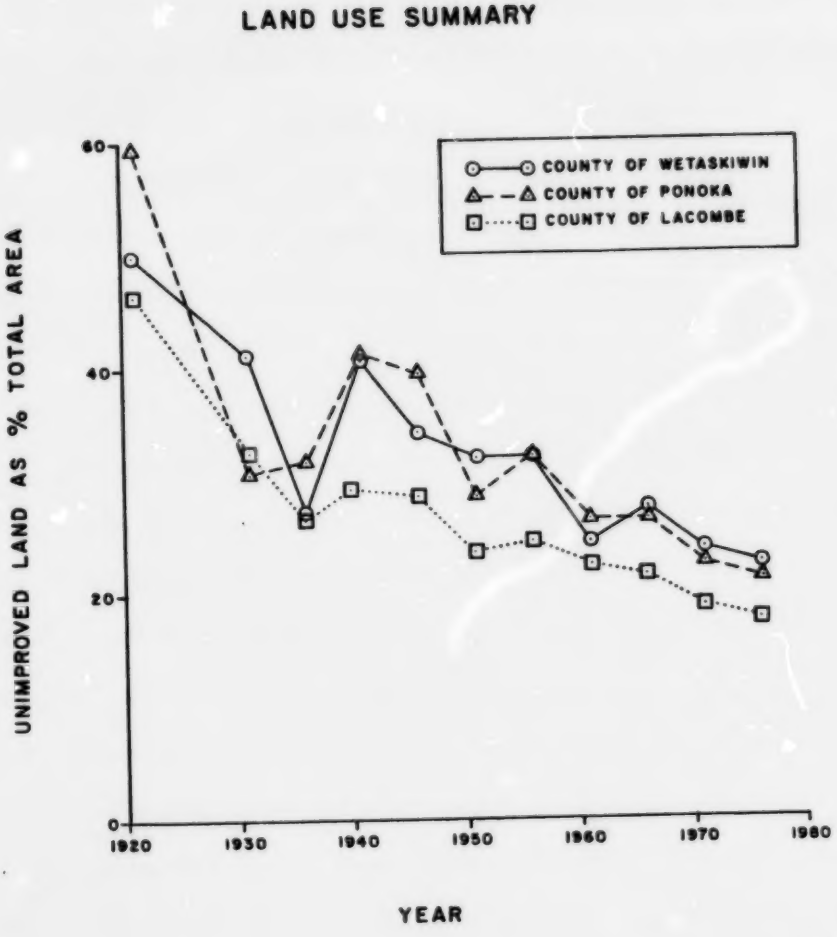

Figure 9. Area of unimproved land versus time, Wetaskiwin, Ponoka, and Lacombe counties, 1921 to 1976.

to changes in county boundaries. For example, this category is considered to include census-farm woodlots, land leased for cutting, cutover land with young growth which has or will have value as timber, fuelwood, or Christmas trees. The area of trees planted for windbreaks is also included but large timber tracts which are operated separately from the census farm are excluded. The main differences in interpretation probably arise in areas of brushland.

4. The area of unimproved land has decreased over time, with Lacombe County having the smallest percentage of unimproved land. This category excludes woodland and includes areas of natural pasture or hay land that had not been cultivated, brush pasture, grazing or waste land, sloughs, marsh land, and rocky land. In 1921, natural pasture represented 45% of the combined area, while waste-land accounted for 6%. The most recent census (1976) indicates that the total unimproved land has decreased to 20% of the combined county area.

5. There has been a strong increase in the area of improved pasture over time for the three counties. This category incorporates all land which has been cultivated and seeded to pasture and was used for grazing. In 1921, this type of land use represented less than 1% of the total area of the three counties but this had increased significantly by 1976 to approximately 15%.

6. The total improved acreage, which is the summation of field crops and improved pasture, has increased at a similar rate for the three counties.

From the preceding, it is evident that the major changes in land use for the upstream portion of the Battle River Basin, from 1921 to 1976, include large increases in cultivated crop acreage and improved pasture with a very substantial decrease in the unimproved land. Although it is not evident how much of the unimproved land was natural pasture in 1976, due to the fact that natural pasture and wasteland were not differentiated in that census year, it is likely that the percentage of wasteland would not have increased from the 1921 census and may have even decreased slightly. Thus, it is reasonable to suggest that in 1976 natural pasture occupied approximately 15% of the combined county area or approximately 116 000 ha compared to 45% of the area or 236 000 ha 1921.

From the census data contained in Appendix 8.3 (Tables 60 to 62), it can be seen that the area contained within the boundaries of the counties of Lacombe, Ponoka, and Wetaskiwin has increased significantly between 1921 and 1976. This increase represents approximately 254 000 ha. It is not clear from the small scale maps available for each census year, however, in which direction the county boundaries have changed but it is probable that most of the expansion has been toward the west as new land was brought into cultivation. This observation may influence the changes in the relative proportions of the various land use categories over time. In spite of this, however, it is believed that the decrease in natural pasture and increase in cultivated land and

improved pasture are still very substantial and far outweigh any decrease in woodland area.

The implications of these land use changes on surface infiltration rates and soil moisture utilization in the Battle River Basin are not completely apparent, mainly because of the unavailability of research data directly related to prairie conditions. It is generally accepted that transpiration is high for woodland due to the high surface infiltration rates and rooting depth of trees and bushes. However, the effects of the conversion of natural pasture to field crops and tame grasses cannot be as clearly stated.

It is likely that the regular cultivation practices of land used for field crops and improved pasture will create higher infiltration rates than is the case for the relatively undisturbed native grasses. Since precipitation has not changed significantly over the period of study, reduced overland flow has occurred and infiltration has increased. The effect of this should be to make more water available for deep percolation to the groundwater zone, all other factors being equal. However, since the water table is declining in the Battle River Basin upstream from Ponoka, it is apparent that deep percolation and groundwater recharge have decreased. This implies that rainfall absorbed by the soil surface must be utilized for transpiration, soil surface evaporation, or increased soil moisture content.

A significant increase in soil moisture content is not likely, however, as in this region of low summer precipitation, available soil moisture will be readily utilized. It is likely that soil moisture

utilization is higher for improved pasture and field crops than for native grasses although this cannot be documented at present. This would account for part of the decreased percolation and lower runoff but by itself would not account for the total decrease in runoff. Increased summer temperatures over the period of record must also be a contributing factor as soil moisture evaporation rates and transpiration have likely increased.

5.2.4 Summary of Streamflow Changes

From the preceding analysis, the following observations can be made concerning the Battle River:

1. Flows in the peak snowmelt month of April have notchanged significantly from the 1914 to 1930 period to the present. This is consistent with the fact that there has been no significant change in winter precipitation for these periods;
2. Streamflows for the Battle River near Ponoka in May and September appear to be responding to a decrease in precipitation intensity;
3. No clear relationship between precipitation and runoff at Ponoka has been established for the month of June;
4. It is doubtful whether the slight decreases in precipitation could account for the significantly reduced runoff in July and August in the more recent period for the Battle River near Ponoka;
5. The decrease in winter flows near Ponoka but not at Battleford indicates that the groundwater table has

declined upstream from Ponoka but apparently not downstream;

6. The slight deforestation that has occurred within the Battle River Basin headwaters since 1921 has not affected runoff significantly; and
7. It is postulated that the conversion of natural pasture to improved pasture and field crops in the Battle River Basin upstream from Ponoka has probably led to a decrease in runoff. Increased infiltration potential, higher transpiration rates, increased soil moisture evaporation, and higher growing season temperatures have been suggested to explain this phenomenon.

5.3 ANALYSIS OF LAKE LEVEL CHANGES

5.3.1 Introduction

The major fluctuations in lake levels in central Alberta have been attributed to a number of causes. These include the effects of climate, the activities of man, and the natural aging process of lakes. Drainage of lakes, either naturally through bedrock fractures or bedrock valleys, or inadvertently through such mechanisms as uncapped seismic holes, has also been suggested to explain declining lake levels. In an attempt to explain the major observed lake level fluctuations within the present study area, each of these hypotheses will be examined.

5.3.2 Climatic Effects

Laycock (1968, 1973) investigated the variations in lake levels for both Gull Lake and Cooking Lake by use of the Thornthwaite

water balance model. This procedure inputs only temperature and precipitation and depends on a number of assumptions and estimations for its validity. For example, groundwater flow into and out of the lake, evaporation from the lake surface, and evapotranspiration from various types of land surfaces within the basin are not easily measured. In fact, Laycock (1973:97) suggested that the major variable in this model is that of soil moisture storage capacity and that "there is a considerable element of guesswork in this material". Essentially, the procedure is one of trial and error, where corrections are applied to evaporation and transpiration and adjustments are made to soil moisture storage such that, for Gull Lake, there is a "running balance over the 52 year period that very closely corresponds to the recorded lake levels" (Laycock 1973:87). For Cooking Lake, there was a "reasonably close correspondence of lake-level changes and calculated changes using Thornthwaite procedures" (Laycock 1973:89).

Laycock (1973) calculated, that for the period 1921 to 1972, Gull Lake levels declined because the tributary drainage area would have had to be three times the lake area instead of twice as large to maintain the earlier lake levels. The fact that Sylvan Lake, which is less than 25 km to the west, has a higher ratio of lake area to total drainage basin area (Table 12), should imply that this lake should have declined more than Gull Lake. This has not occurred. Therefore, it is likely that the Thornthwaite model would not apply as well to Sylvan as it apparently has to both Gull and Cooking lakes. Laycock (1973) states in his study that it was by no means exhaustive in scope. It is apparent that a detailed inventory of land use changes was not included

as a major component of the study. If this is true, then the results of the application of the Thornthwaite model may not be too reliable in this case. It is clear, however, that since there is a high level of correlation between mean annual Sylvan and Gull lake levels during the last 25 years of record, these lakes are behaving in a similar fashion and not in isolation from each other.

The exact mechanism that controls changes in lake elevation is not evident. From the analysis of precipitation and temperature variables in Section 4, it has been shown that there is no consistent significant change in these variables from the 1914 to 1930 period to the present. Although the lakes must be responding to climatic influences, it would appear that, given the character of the available data, any attempt to explain fluctuations in lake levels in terms of the composite effects of climatic variables would meet with only limited success.

The complex interrelationships between climate and lake levels is emphasized by the lack of relationship between lake levels and streamflow as recorded for Battle River near Ponoka from 1967 to 1976. Although it is realized that many of the lakes are just outside the Battle River Basin, it is felt that lake levels and streamflow should be responding to fairly widespread climatic conditions rather than to localized effects, and therefore, this type of analysis is justifiable. From Table 47, it is apparent that no clear relationship exists between lake levels and flows for the Battle River area.

Table 47. Correlation of selected lake levels with flows for the Battle River near Ponoka, 1967 to 1976.

	LAKE LEVEL	MEAN FLOW	R	SIGNIFICANCE LEVEL (%)
GULL	May	May	0.385	-
	May	April	0.196	-
	October	October	0.381	-
	Mean Annual	Annual	0.306	-
SYLVAN	May	May	0.720	5
	May	April	0.531	-
	October	October	0.776	1
	Mean Annual	Annual	0.715	5
PIGEON	May	May	0.753	1
	May	April	0.386	-
	October	October	0.254	-
	Mean Annual	Annual	0.339	-
BATTLE	May	May	0.637	5
	May	April	0.614	5
	October	October	-0.025	-

5.3.3 Activities of Man

The hydrology of lakes may be altered by artificial drainage and impoundment. From the available records, however, as well as from the consideration that the study area lakes are highly oriented towards recreation, it is apparent that any lake level declines have not been due to artificial drainage. In fact, attempts have been made to arrest declining levels for Gull Lake which has received water from the Blindman River since 1976 via a pumping operation. However, the quantities involved [2.2 x 106 m^3 in 1976; 3.4 x 106 m^3 in 1977; 5.7 x 106 m^3 in 1978; and 3.3 x 106 m^3 in 1979 (personal communication, W.E. Kerr, Alberta Environment, Hydrology Branch)] had very little effect in stabilizing the level of Gull Lake. Similar schemes have been proposed for other lakes in central Alberta, such as Cooking Lake.

Several specific studies relating to the effects of changes in land use on lake elevations in central Alberta have been undertaken but are contradictory. For example, Laycock (1973) suggests that the clearing and burning of forest cover in the Cooking Lake Basin probably contributed to very high water yields into the lake prior to 1930 and that the area now has second growth which consumes as much as a mature cover might, thus decreasing the yields. This conclusion is not supported by the Cooking Lake Area Study (Alberta Environment 1976) which investigated the relationship between land development and lake levels for Miquelon, Cooking, Hastings, and Pigeon. It was concluded that deforestation has probably not been a major factor in declining lake levels since,

> all the lakes, with the exception of Hastings, have declined at approximately the same rate, whilst subject to varying

> degrees of deforestation due to land development. If deforestation played a significant part in decline of lake levels one would expect the rate of decline to be a functionof the amount of change in land use. This is not evident from the information available (Alberta Environment 1976:71).

Finally, if the hypothesis, that reduced summer streamflow for the Battle River is related to an increase in cultivated land and improved pasture and a decrease in natural pasture, is valid, then lake levels may also be responding to this phenomenon. However, since lake level records prior to the 1956 census are too discontinuous to be reliably used, any verification of this hypothesis for declining lake levels must be based primarily on the census years of 1956, 1961, 1971, and 1976. In this period, it can be seen from Figures 4 to 9 that the southern-most county (Lacombe) has the most developed agricultural acreage, the lowest proportion of unimproved land, and the smallest woodland area, while the County of Wetaskiwin to the north tends to be the reverse. This may imply that the effects on the lake levels should be more pronounced for Sylvan Lake and Gull Lake and less pronounced for the more northerly Pigeon Lake. From the records of mean annual lake levels (Appendix 8.2, Tables 55 to 59), it can be seen that this may indeed be the case: mean annual lake level for Pigeon Lake has risen 1.10 m from 1956 to 1976 and has declined 1.48 m for Sylvan Lake and 1.52 m for Gull Lake during the same period. Caution should be exercised in this interpretation, however, as Wabamun Lake to the northwest has declined 1.25 m in the same period. Whether land use outside the county area examined has changed in a similar fashion has not been verified.

5.3.4 Natural Processes

Lake levels may decline because of natural erosion of an outlet channel. If this mechanism were operating, then erosion would be a continuous process and lake levels would continue to decline and any short-term rise in lake level would be due to surcharge storage while the outlet was discharging. Of all the study lakes, the only lakes which have recent levels much below earlier maximum recorded levels include Pigeon, Sylvan, Gull, Miquelon, and Cooking. However, records of the outlet elevations of these lakes are not generally available, so it is impossible to determine how much effect erosion may have had. In all likelihood, outlet erosion would not account for much of the variation in lake level, as in many cases (Gull, Sylvan, and Pigeon, for example), the present lake elevation is below the outlet elevation and, according to Nielsen (1963), Gull Creek for example, ceased to drain Gull Lake into Blindman River in the 1920's.

5.3.5 Groundwater Geology

Other hypotheses advanced to explain the decline in lake levels in central Alberta, especially Gull Lake, include bedrock fractures, buried channels, and seismic exploration.

Most wells in the vicinity of Gull Lake are less than 60 m deep and are completed in the Paskapoo Formation. This formation is non-marine in origin and consists primarily of soft shale, clay, and sandstone. The sandstone exists as lenses, some of which can be traced up to 10 km but most have an extent of less than 1.5 km. From drilling logs, these lenses appear to be disconnected but there is obviously sufficient hydraulic conductivity in the intervening material to allow

recharge to wells (Nielsen 1963). There is no indication that the bedrock within the Gull Lake area is fractured to the extent that relatively rapid lake drainage would be possible.

Nielsen (1963) investigated the ground water resources of Blindman River Valley and its relationship to Gull Lake. From his study of surficial deposits and bedrock topography, he concluded that there were originally two streams in the Blindman Basin. The easterly stream followed a 3 km wide, 60 m deep bedrock channel southward into present Gull Lake. The southern part of this channel became dammed with a poorly sorted hummocky moraine and diverted the stream to the present Blindman River Valley to the west. Gull Lake was probably of glacial origin being formerly much larger than at present. A small poorly defined eastern channel probably drained glacial Gull Lake for a short time into adjacent glacial Lake Red Deer. Nielsen also concluded that, since the northerly Gull Lake Channel cannot be traced down the regional slope to the Red Deer River, large scale groundwater seepage out of the Gull Lake Basin is unlikely.

Because of the small drainage areas of many of the study lakes, it is felt that many of the lakes are fed partly by springs. Examples of these lakes include Battle (Battle River Regional Planning Commission 1974), Sylvan, and Gull lakes. Fritz and Krouse (1973) concluded that, since the total dissolved solids of Wabamun Lake are low even though evaporation is much higher than surface inflow to the lake, significant flushing from the Paskapoo sandstone must occur.

An observation well completed at the north end of Gull Lake in 1965 illustrates the interrelationships between Gull Lake levels and

groupwater levels (see Appendix 8.4, Tables 63 to 66). It can be observed that lake elevation and groundwater level co-vary. The correlation coefficient for daily lake and groundwater levels for Gull Lake is 0.829 (29 observations), while the coefficient for daily lake levels and groundwater levels recorded on the day following the lake level reading is 0.782 (28 observations). Finally, the correlation coefficient between mean monthly levels is 0.806 (31 observations). Clearly, Gull Lake levels are directly related to the groundwater conditions but a lack of information for other lakes makes it impossible to confirm this relationship with certainty elsewhere within the study area.

Finally, there is a feeling expressed by some of the residents of the Gull Lake area that seismic shotholes in the vicinity of the lake have adversely affected nonpumping water well levels as well as Gull Lake itself. While it has not been documented how much the well levels have declined, it would appear that if seismic shotholes penetrate the uppermost sandstone aquifer, it is possible that water may drain from one lens to lower ones if these lenses are not grouted. However, all shotholes are at least capped, therefore, it is difficult to understand how a surface water body could be affected by seismic work. Furthermore, from analysis of the volumes of water available from flowing wells at the north end of Gull Lake, it would require 400 artesian wells each producing at least 20 L/min to stabilize the lake level decline (Nielsen 1963). Thus, it would appear that seismic shotholes could not explain the large volume of water lost from Gull

Lake during the period of record. The correlations of Gull Lake levels with those of Sylvan Lake must also discount this theory.

With regard to the geology of Cooking Lake (Alberta Environment 1976) it was concluded that groundwater outflow is possible through two buried bedrock channels trending eastward from the lake. However, calculations indicate that this may amount to about 0.24 mm/year. Although the accuracy of this figure is questionable due to some very gross assumptions, it is clear, that in all probability, the seepage losses could not in themselves completely explain lake level trends for this lake. Unfortunately, information on the other study lakes is unavailable.

5.3.6 Summary of Lake Level Changes

The relationships between the levels of the lakes selected for analysis in this thesis and the factors which influence these levels can be summarized as follows:

1. No clear relationships exist between Battle River flows and lake levels during the periods analyzed. This indicates the complexity among climate, land use, and other factors.
2. Long term declines in lake levels could not be directly related to precipitation.
3. It is unclear from previous studies (Laycock 1973; Alberta Environment 1976) whether lake level declines can be attributed to deforestation. However, since most lake level records have only been available in the last 25 years, it is unlikely that deforestation has affected

lake levels significantly. The effect of other land use changes may be more important. The replacement of natural pasture by improved pasture and field crops in conjunction with higher growing season temperatures may offer a partial explanation for lake level changes (see Section 5.2.4).

4. The decline in Gull Lake levels cannot be attributed to outlet erosion, artificial drainage, buried bedrock valleys, bedrock fractures, or seismic exploration. It is probable that these conclusions can be applied to the other lakes in central Alberta but data are unavailable.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

6.1.1 Streamflow Regime

The following conclusions regarding the hydrologic regime of the Battle River have been reached:

1. Analysis of mean annual runoff volumes for the 1914 to 1930 and 1967 to 1976 periods indicates that flows have decreased significantly at Ponoka but not at Battleford. Monthly streamflows for Ponoka, except for April and September, are also significantly lower in the recent period. This indicates that the regime of the Battle River above Ponoka has changed.
2. These regime changes can only be partly explained by the analysis of precipitation recorded at Lacombe and Wetaskiwin. Constant April flows at Ponoka are consistent with unchanged winter precipitation, and reduced streamflows in May and September may be responding to a decrease in the mean storm intensity. No clear relationships between precipitation and runoff are indicated for June, July, and August.
3. It was concluded that the slight deforestation which has occurred within the Battle River Basin headwaters since 1921 could not have affected runoff significantly. Other changes in land use may be quite significant. It has been postulated that higher growing season temperatures and the

conversion of natural pasture to improved pasture and field crops may have led to a decrease in runoff. This decrease may be related to higher transpiration rates, increased infiltration potential, and increased soil moisture evaporation in the basin upstream from Ponoka.

6.1.2 Lake Level Trends

From the analysis of lake levels in central Alberta, it can be concluded that:

1. The 5 year moving-mean, linear trend, and correlation analyses indicate regional similarities in trends for many of the lakes in central Alberta. Cooking, Hastings, Pigeon, Wabamun, and Gull lakes have shown similar moving-mean trends. From the linear trend relationships, it has been noted that the rate of decline of Gull Lake has decreased substantially in recent years. With respect to Gull Lake, significant correlations exist in mean annual lake levels between Gull and Buffalo, Sylvan, Pigeon, and Wabamun (1956 to 1966 period) and between Gull and Sylvan only in the 1967 to 1978 period. This suggests that Gull Lake is responding to regional effects of climate, land use, and geology, and that the region of similarity has apparently decreased in the more recent period.
2. The poor correlations between lake levels and Battle River flows suggest that the composite effects of climatic and land use variables on runoff are complex. Deforestation within the Battle River Basin since 1956 has had no

apparent effect on lake levels. The decline in lake levels, especially for Gull and Sylvan, is related to lower groundwater levels in the region and the reduction in overland flow in the recent record. It is probable that both these factors are related to the aforementioned changes in land use.

3. Variations in elevation for Gull Lake are not related to artificial drainage, natural erosion of an outlet channel, buried valleys, bedrock fractures, or seismic exploration. It is probable that similar conclusions can be applied to the other lakes in central Alberta, although data are not readily available.

6.2 RECOMMENDATIONS

The analysis of streamflow records for the Battle River near Ponoka for the 1914 to 1930 and 1967 to 1976 periods has demonstrated that the data are not homogeneous. It is not possible, therefore, to reconstruct flows from 1930 to 1967 as it is impossible to tell how rapidly the regime has changed. For planning purposes, it is recommended that only the latest period of record be used.

Battle River flows and levels are responding to regional effects of climate and land use. This implies that increased streamflows and higher lake levels could only occur after a sequence of years of above normal precipitation. For Gull Lake in particular, the observed trend toward a lower annual decline in level offers some hope that water importation may assist lake level stabilization but it is

likely that the return to the former high levels will not be easily achieved.

This thesis has indicated that utilization of soil moisture by different types of vegetation may affect surface runoff and percolation. Research on this topic appears to be limited and further investigation may be warranted.

Finally, the apparent changes in groundwater levels in the Battle River Basin upstream from Ponoka and no evident decline downstream suggest that a more detailed examination of the groundwater conditions for the entire basin may be useful. This would require a detailed study of geology as well as the evaluation of well records.

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8. APPENDIX

8.1 MOVING-MEAN LAKE ELEVATIONS

Five-year May and October moving mean lake elevations for the available periods of record are presented in Tables 48 to 52 for Battle, Cooking, Gull, Hastings, Pigeon, Sylvan, and Wabamun lakes.

Table 48. Five-year moving mean elevations, Cooking Lake (1968 to 1978) and Battle Lake (1967 to 1978).

	YEAR	ELEVATION (m) MAY	OCTOBER
Cooking Lake	1968		735.63
	1969	735.70	735.48
	1970	735.58	735.40
	1971	735.57	735.39
	1972	735.67	735.53
	1973	735.82	735.66
	1974	735.95	735.80
	1975	736.06	735.90
	1976	736.12	735.98
	1977	736.12	735.95
	1978	736.08	735.92
Battle Lake	1967		836.50
	1968		836.47
	1969		836.41
	1970		836.37
	1971		836.43
	1972		836.37
	1973		836.33
	1974		836.38
	1975		836.46
	1976		836.53
	1977		836.60
	1978		836.72

Table 49. Five-year moving mean elevations, Gull Lake (1956 to 1978) and Hastings Lake (1967 to 1978).

	YEAR	ELEVATION (m) MAY	OCTOBER
Gull Lake	1956	900.17	
	1957	900.13	899.93
	1958	900.00	899.80
	1959	899.84	899.64
	1960	899.66	899.47
	1961	899.48	899.31
	1962	899.36	899.18
	1963	899.30	899.13
	1964	899.29	899.12
	1965	899.28	899.08
	1966	899.25	899.06
	1967	899.20	899.01
	1968	899.08	898.88
	1969	898.97	898.77
	1970	898.89	898.72
	1971	898.86	898.70
	1972	898.90	898.74
	1973	898.95	898.76
	1974	898.94	898.73
	1975	898.91	898.69
	1976	898.86	898.67
	1977	898.81	898.61
	1978	898.72	898.56
Hastings Lake	1967	736.07	735.93
	1968	735.97	735.74
	1969	735.81	735.60
	1970	735.67	735.50
	1971	735.61	735.46
	1972	735.63	735.57
	1973	735.72	735.72
	1974	735.98	735.85
	1975	736.11	735.96
	1976	736.21	736.06
	1977	736.22	736.04
	1978	736.17	736.99

Table 50. Five-year moving mean elevations, Pigeon Lake, 1962 to 1978.

YEAR	ELEVATION (m) MAY	OCTOBER
1962	849.71	
1963	849.67	
1964	849.58	
1965	849.63	
1966	849.57	
1967	849.60	849.61
1968	849.62	849.52
1969	849.59	849.51
1970	849.58	849.52
1971	849.69	849.60
1972	849.85	849.75
1973	849.99	849.87
1974	850.08	849.93
1975	850.17	849.98
1976	850.20	850.00
1977	850.15	849.95
1978	850.09	849.93

Table 51. Five-year moving mean elevations, Sylvan Lake, 1920 to 1930 and 1958 to 1978.

YEAR	ELEVATION (m) MAY	OCTOBER
1920		936.63
1921	936.75	936.63
1922	936.70	936.64
1923	936.64	936.62
1924	936.61	936.63
1925	936.72	936.73
1926	936.80	936.78
1927	936.85	936.77
1928	936.85	936.76
1929	936.89	936.78
1930	936.81	936.65
1958		936.60
1959	936.68	936.52
1960	936.56	936.43
1961	936.45	936.35
1962	936.38	936.26
1963	936.32	936.24
1964	936.34	936.26
1965	936.40	936.29
1966	936.42	936.33
1967	936.49	936.40
1968	936.42	936.39
1969	936.52	936.36
1970	936.52	936.38
1971	936.58	936.41
1972	936.62	936.46
1973	936.68	936.48
1974	936.68	936.47
1975	936.66	936.43
1976	936.61	936.39
1977	936.57	936.34
1978	936.50	936.30

Table 52. Five-year moving mean elevations, Wabamun Lake, 1936 to 1955 and 1962 to 1978.

YEAR	ELEVATION (m) MAY	OCTOBER
1936	724.61	724.38
1937	724.58	724.33
1938	724.52	724.25
1939	724.39	724.19
1940	724.33	724.17
1941	724.34	724.23
1942	724.41	724.33
1943	724.42	724.33
1944	724.43	724.32
1945	724.45	724.31
1946	724.51	724.29
1947	724.46	724.24
1948	724.46	724.21
1949	724.43	724.21
1950	724.42	724.23
1951	724.34	724.27
1952	724.39	724.37
1953	724.44	724.45
1954	724.49	724.53
1955	724.58	724.61
1962		724.01
1963		724.11
1964		724.05
1965		724.10
1966		724.11
1967		724.13
1968	724.46	724.01
1969	724.36	723.96
1970	724.34	723.97
1971	724.36	724.03
1972	724.51	724.14
1973	724.58	724.23
1974	724.64	724.23
1975	724.63	724.24
1976	724.62	724.29
1977	724.51	724.44
1978	724.48	724.44

8.2 MEAN ANNUAL LAKE LEVELS

Mean annual lake levels for Gull, Sylvan, Pigeon, Buffalo, and Wabamun lakes, 1953 to 1978, are presented in Tables 53 to 57.

Table 53. Mean annual lake levels, Gull Lake, 1955 to 1978.

YEAR	NUMBER OF READINGS	ANNUAL MEAN LEVEL (m)
1955	3	900.26
1956	3	900.23
1957	3	900.08
1958	3	899.94
1959	2	899.70
1960	2	899.62
1961	3	899.42
1962	2	899.24
1963	4	899.08
1964	2	899.05
1965	4	899.31
1966	4	899.31
1967	5	899.05
1968	4	898.85
1969	6	898.80
1970	8	898.77
1971	7	898.76
1972	8	898.78
1973	8	898.79
1974	7	898.93
1975	8	898.88
1976	8	898.71
1977	5	898.58
1978	4	898.59

Table 54. Mean annual lake levels, Sylvan Lake, 1956 to 1978.

YEAR	NUMBER OF READINGS	ANNUAL MEAN LEVEL (m)
1956	3	936.93
1957	3	936.78
1958	4	936.70
1959	4	936.55
1960	6	936.55
1961	3	936.48
1962	4	936.31
1963	4	936.17
1964	6	936.12
1965	5	936.32
1966	2	936.51
1967	8	936.49
1968	7	936.39
1969	6	936.45
1970	7	936.44
1971	7	936.49
1972	9	936.52
1973	8	936.57
1974	8	936.65
1975	8	936.62
1976	8	936.45
1977	8	936.36
1978	9	936.35

Table 55. Mean annual lake levels, Pigeon Lake, 1953 to 1978.

YEAR	NUMBER OF READINGS	ANNUAL MEAN LEVEL (m)
1953	2	850.09
1954	4	850.18
1955	4	850.13
1956	3	850.00
1957	3	849.92
1958	1	849.83
1959	1	849.73
1960	1	849.69
1961	2	849.59
1962	3	849.50
1963	2	849.50
1964	1	849.43
1965	4	849.67
1966	4	849.77
1967	2	849.72
1968	4	849.47
1969	3	849.53
1970	3	849.50
1971	4	849.62
1972	3	849.70
1973	0	-
1974	4	850.32
1975	5	850.27
1976	7	850.10
1977	7	850.05
1978	4	850.08

Table 56. Mean annual lake levels, Buffalo Lake, 1957 to 1978.

YEAR	NUMBER OF READINGS	ANNUAL MEAN LEVEL (m)
1957	1	901.03
1958	2	900.79
1959	1	900.56
1960	0	-
1961	2	900.10
1962	1	899.89
1963	1	899.86
1964	1	899.68
1965	3	899.98
1966	4	899.97
1967	3	899.90
1968	3	899.71
1969	4	899.73
1970	3	899.92
1971	3	900.12
1972	3	900.19
1973	6	900.28
1974	1	900.94
1975	0	-
1976	4	900.78
1977	5	900.69
1978	1	900.62

Table 57. Mean annual lake levels, Wabamun Lake, 1953 to 1978.

YEAR	NUMBER OF READINGS	ANNUAL MEAN LEVEL (m)
1953	2	723.04
1954	2	723.25
1955	2	723.13
1956	2	723.13
1957	2	722.97
1958	2	722.78
1959	2	722.65
1960	2	722.68
1961	3	722.49
1962	5	722.49
1963	4	722.63
1964	4	722.54
1965	4	722.87
1966	6	723.13
1967	5	722.99
1968	4	722.72
1969	8	722.64
1970	7	722.62
1971	6	722.72
1972	12	722.92
1973	12	722.92
1974	12	723.18
1975	12	723.03
1976	12	722.88
1977	12	722.89
1978	12	722.96

8.3 LAND USE CENSUS DATA

Agricultural land use changes, as obtained from Alberta census data for the counties of Wetaskiwin, Ponoka, and Lacombe, are presented in Tables 58 to 60.

Table 58. Agricultural land use changes for the county of Wetaskiwin, Alberta.[a]

YEAR	MUNICIPALITY TWP SUBDIVISION	FIELD CROPS	IDLE OR FALLOW	IMP. PASTURE	WOOD-LAND	NATURAL PASTURE	MARSH OR WASTE	TOTAL AREA
1921	458	24 702	4 466	540	11 685	43 566	4 220	89 179
	459	8 591	1 158	36	21 602	10 456	5 180	47 023
	460	1 011	278	124	1 433	7 330	1 953	12 129
	461	393	108	0	469	3 692	334	4 966
	TOTAL	36 698	6 010	700	35 189	65 044	11 687	153 327
	%	22.6	3.9	0.5	23.0	42.4	7.6	100.0
1931	458	41 702	6 888	2 666	12 030	18 672	3 404	84 362
	459	21 450	2 387	987	7 853	27 807	3 367	63 851
	460	2 142	410	97	7 447	4 887	1 695	17 648
	461	1 453	76	64	367	10 387	1 185	13 532
	TOTAL	66 747	9 761	3 814	27 667	62 753	9 651	180 339
	%	37.0	5.4	2.1	15.3	34.8	5.3	99.9

Continued...

Table 58. Continued.

YEAR	MUNICIPALITY TWP SUBDIVISION	FIELD CROPS	IDLE OR FALLOW	IMP. PASTURE	WOOD-LAND	NATURAL PASTURE	MARSH OR WASTE	TOTAL AREA
1936	458	42 338	10 536	2 665	8 790	19 429	5 015	88 773
	459	24 799	5 945	798	14 906	21 666	3 427	71 541
	460	3 192	940	208	17 775	1 007	2 292	25 414
	461	2 127	465	30	13 566	531	1 965	18 684
	TOTAL	72 456	17 886	3 701	55 037	42 633	12 699	204 412
	%	35.4	8.8	1.8	26.9	20.9	6.2	100.0
1941	458	43 213	13 890	3 179	7 507	18 618	3 330	89 737
	459	29 515	8 825	1 225	10 270	28 334	1 646	79 815
	460	4 607	1 134	210	4 569	19 402	1 391	31 313
	461	3 480	640	238	349	16 649	1 810	23 166
	TOTAL	80 815	24 489	4 852	22 695	83 003	8 177	224 031
	%	36.1	10.9	2.2	10.1	37.1	3.6	100.0

Continued...

Table 58. Continued.

YEAR	MUNICIPALITY TWP SUBDIVISION	CROPS	IDLE OR FALLOW	IMP. PASTURE	WOOD-LAND	NATURAL PASTURE	MARSH OR WASTE	TOTAL AREA
1946	458	40 906	14 356	4 202	4 888	19 854	2 337	86 543
	459	28 825	10 272	2 958	13 150	20 690	1 324	77 219
	460	5 756	1 056	207	9 381	11 976	2 001	30 377
	461	3 754	463	126	1 705	14 983	465	21 496
	TOTAL	79 241	26 147	7 493	29 124	67 503	6 127	15 635
	%	36.7	12.1	3.5	13.5	31.3	2.8	99.9
1951	458	46 866	13 082	3 932	4 515	20 482		88 877
	459	34 310	8 896	3 635	6 733	28 700		82 274
	460	7 385	1 563	458	17 579	10 381		37 366
	461	5 309	837	269	2 863	15 389		24 667
	TOTAL	93 970	24 378	8 294	31 690	74 952		233 184
	%	40.3	10.5	3.6	13.6	32.1		100.1

Continued...

Table 58. Concluded.

YEAR	MUNICIPALITY TWP SUBDIVISION	FIELD CROPS	IDLE OR FALLOW	IMP. PASTURE	WOOD-LAND	NATURAL PASTURE	MARSH OR WASTE	TOTAL AREA
1956	TOTAL	91 037	22 918	11 415	26 879	71 993		224 242
	%	40.6	10.2	5.1	12.0	32.1		100.0
1961	TOTAL	98 458	25 715	15 728	28 242	54 750		222 893
	%	44.2	11.5	7.1	12.7	24.6		100.1
1966	TOTAL	112 641	22 181	23 244	25 074	69 744		252 884
	%	44.5	8.8	9.2	9.9	27.6		100.0
1971	TOTAL	119 349	24 827	29 884	25 760	63 251		263 071
	%	45.4	9.1	11.4	9.8	24.0		100.0
1976	TOTAL	118 202	20 696	40 317	20 630	57 389		257 234
	%	46.0	8.0	15.7	8.0	22.3		100.0

[a] in hectares.

Table 59. Agricultural land use changes for the county of Ponoka, Alberta.[a]

YEAR	MUNICIPALITY TWP SUBDIVISION	FIELD CROPS	IDLE OR FALLOW	IMP. PASTURE	WOOD-LAND	NATURAL PASTURE	MARSH OR WASTE	TOTAL AREA
1921	428	12 226	2 641	337	3 568	19 673	2 604	41 046
	429	17 440	2 649	95	3 346	34 495	4 614	62 639
	430	8 828	1 913	113	6 148	13 225	2 913	33 140
	431	4 825	726	24	1 165	15 768	1 852	24 360
	TOTAL	43 319	7 929	569	14 224	83 161	11 983	161 185
	%	27.2	5.0	0.4	7.7	52.2	7.5	100.0
1931	428	18 888	5 327	890	7 983	10 731	1 784	45 603
	429	30 370	3 767	1 110	15 284	19 489	4 648	74 668
	430	14 373	3 228	865	9 663	9 618	1 981	39 728
	431	8 830	2 054	137	8 427	7 524	2 045	29 017
	TOTAL	72 461	14 376	3 002	41 357	47 362	10 458	189 016
	%	38.3	7.6	1.6	21.9	25.1	5.5	100.0

Continued...

Table 59. Continued.

YEAR	MUNICIPALITY TWP SUBDIVISION	FIELD CROPS	IDLE OR FALLOW	IMP. PASTURE	WOOD-LAND	NATURAL PASTURE	MARSH OR WASTE	TOTAL AREA
1936	428	19 369	6 426	813	4 438	15 760	970	47 776
	429	30 582	7 553	1 411	10 094	24 757	3 290	77 687
	430	14 559	5 553	855	13 024	10 630	2 153	46 774
	431	10 856	3 559	621	19 449	6 722	4 810	46 017
	TOTAL	75 366	23 091	3 700	47 005	57 869	11 223	218 254
	%	34.5	10.6	1.7	21.5	26.5	5.1	99.1
1941	428	19 037	8 218	1 157	3 385	14 109	1 634	47 540
	429	32 672	10 770	1 903	9 373	24 617	2 131	80 466
	430	16 481	6 851	745	245	27 747	1 296	53 365
	431	12 576	4 009	694	5 308	17 537	3 905	44 029
	TOTAL	80 766	29 848	4 499	17 311	84 010	8 966	225 400
	%	35.8	13.2	2.0	7.7	37.3	4.0	100.0

Continued...

Table 59. Continued.

YEAR	MUNICIPALITY TWP SUBDIVISION	FIELD CROPS	IDLE OR FALLOW	IMP. PASTURE	WOOD-LAND	NATURAL PASTURE	MARSH OR WASTE	TOTAL AREA
1946	428	18 940	8 861	1 476	4 126	13 150	1 947	48 500
	429	30 016	11 535	3 248	8 654	20 468	4 062	77 983
	430	16 113	6 313	2 272	1 644	26 683	958	53 983
	431	14 003	4 205	690	5 492	21 828	1 531	47 749
	TOTAL	79 072	30 914	7 686	19 916	82 129	8 498	228 215
	%	34.7	13.5	3.3	8.7	35.0	3.7	99.9
1951	428	20 186	7 254	1 891	2 285	14 324		46 240
	429	36 920	10 754	3 293	9 366	20 231		80 564
	430	18 499	6 489	2 405	13 310	12 815		53 518
	431	15 434	3 824	1 073	10 618	18 378		49 327
	TOTAL	91 039	28 321	8 662	25 879	65 748		229 649
	%	39.6	12.3	3.8	15.6	28.6		99.9

Continued...

Table 59. Concluded.

YEAR	MUNICIPALITY TWP SUBDIVISION	FIELD CROPS	IDLE OR FALLOW	IMP. PASTURE	WOOD-LAND	NATURAL PASTURE	MARSH OR WASTE	TOTAL AREA
1956	TOTAL	94 294	28 740	11 673	24 479	75 464		234 650
	%	40.2	12.2	5.0	10.4	32.2		100.0
1961	TOTAL	102 811	28 524	15 334	28 510	62 416		237 595
	%	43.3	12.0	6.5	12.0	26.3		100.1
1966	TOTAL	119 762	25 662	25 662	21 752	69 236		261 735
	%	45.8	9.7	9.8	8.3	26.5		100.1
1971	TOTAL	126 967	23 219	31 760	17 515	58 345		257 806
	%	49.2	9.0	12.3	6.8	22.6		99.9
1976	TOTAL	127 170	16 123	40 487	18 699	54 709		257 188
	%	49.4	6.3	15.7	7.3	21.3		100.0

[a] in hectares.

Table 60. Agricultural land use changes for the County of Lacombe, Alberta.[a]

YEAR	MUNICIPALITY TWP SUBDIVISION	FIELD CROPS	IDLE OR FALLOW	IMP. PASTURE	WOOD-LAND	NATURAL PASTURE	MARSH OR WASTE	TOTAL AREA
1921	398	20 885	5 152	866	10 505	35 126	4 874	77 408
	299	29 559	3 715	1 098	13 343	35 789	2 962	86 466
	400	15 953	3 187	11	11 344	19 747	1 225	51 467
	TOTAL	66 397	12 054	1 975	35 192	30 662	9 061	215 341
	%	30.8	5.6	0.9	16.3	42.1	4.2	99.0
1931	398	30 321	5 629	1 478	6 955	34 409	3 475	82 355
	399	44 723	8 422	3 537	14 324	12 059	2 459	98 574
	400	24 477	6 691	1 525	13 324	12 059	2 459	60 535
	TOTAL	99 521	20 742	6 540	35 100	70 681	8 880	241 464
	%	41 6	8.7	2.7	14.7	29.5	2.9	100.1

Continued...

Table 60. Continued.

YEAR	MUNICIPALITY TWP SUBDIVISION	FIELD CROPS	IDLE OR FALLOW	IMP. PASTURE	WOOD-LAND	NATURAL PASTURE	MARSH OR WASTE	TOTAL AREA
1936	398	31 285	7 917	1 603	18 670	28 227	2 792	90 494
	399	45 684	10 561	3 770	15 432	22 906	2 386	100 689
	400	28 197	8 124	2 098	16 458	9 410	2 226	66 513
	TOTAL	105 116	26 602	7 471	50 560	60 543	7 404	257 696
	%	40.1	10.4	2.9	19.6	23.5	2.9	100.0
1941	398	30 847	12 429	1 629	13 186	31 709	2 193	91 993
	399	48 898	15 521	4 172	8 083	26 739	3 363	105 776
	400	31 445	12 089	1 903	12 255	13 334	1 570	72 596
	TOTAL	111 190	40 039	7 704	32 524	71 782	7 126	270 365
	%	41.2	14.8	2.8	12.0	26.5	2.6	99.9

Continued...

Table 60. Continued.

YEAR	MUNICIPALITY TWP SUBDIVISION	FIELD CROPS	IDLE OR FALLOW	IMP. PASTURE	WOOD-LAND	NATURAL PASTURE	MARSH OR WASTE	TOTAL AREA
1946	398	29 665	12 393	2 414	10 330	34 930	3 100	92 832
	399	48 545	16 989	4 464	9 253	25 443	1 376	106 070
	400	31 541	12 389	2 981	14 245	12 188	851	74 195
	TOTAL	109 751	41 771	9 859	33 828	72 561	5 327	273 097
	%	40.2	15.3	3.6	12.4	26.6	2.0	100.1
1951	398	32 488	13 812	4 728	9 036	29 370		88 343
	399	54 044	17 122	4 868	11 544	17 573		105 151
	400	36 494	11 127	2 555	7 420	16 589		74 185
	TOTAL	123 026	42 061	12 151	27 000	63 532		267 770
	%	45.9	15.7	4.5	10.1	23.7		99.9

Continued...

Table 60. Concluded.

YEAR	MUNICIPALITY TWP SUBDIVISION	FIELD CROPS	IDLE OR FALLOW	IMP. PASTURE	WOOD-LAND	NATURAL PASTURE	MARSH OR WASTE	TOTAL AREA
1956	TOTAL	123 049	42 311	13 865	22 140	64 975		266 340
	%	46.2	15.9	5.2	8.3	24.4		100.0
1961	TOTAL	132 348	40 656	17 080	16 846	60 440		267 370
	%	49.5	15.2	6.4	6.3	22.6		100.0
1966	TOTAL	150 316	32 075	22 263	11 947	59 919		276 520
	%	54.4	11.6	8.1	4.3	21.7		100.1
1971	TOTAL	148 373	32 409	29 144	12 763	51 421		274 110
	%	54.1	11.8	10.6	4.7	18.8		100.0
1976	TOTAL	154 354	22 216	35 435	12 967	47 605		270 577
	%	57.0	8.2	12.4	4.8	17.6		100.0

[a] in hectares.

8.4 GROUNDWATER AND LAKE LEVELS

Data on groundwater levels from an observation well north of Gull Lake, and Gull Lake levels from 1965 to 1978, are presented in Tables 61 to 64.

Table 61. Relationship between daily Gull Lake elevation (m) and observation well water level below assumed datum (m), 1965 to 1978.

YEAR	GULL LAKE DATE	GULL LAKE LEVEL (m)	OBSERVATION WELL DEPTH (m)
1965	Aug. 18	899.41	32.81
	Sept. 28	899.36	32.84
	Nov. 4	899.32	32.89
1967	Nov. 9	898.93	33.54
1968	May 6	899.00	33.62
	Oct. 1	898.84	33.70
1969	Oct. 28	898.72	33.73
1970	May 28	898.81	33.67
	Oct. 16	898.65	33.63
1971	Mar. 25	898.77	33.65
	May 17	898.88	33.70
	Oct. 16	898.69	33.73
1972	Mar. 22	898.74	33.67
	June 27	898.90	33.63
	Nov. 2	898.72	33.70
1973	May 17	898.87	33.68
	Nov. 5	898.73	33.74
1974	Nov. 7	898.89	33.58
1975	Mar. 5	898.89	33.68
	May 16	899.07	33.61
	Oct. 28	898.76	33.67
1976	May 18	898.84	33.61
	Oct. 27	898.55	33.63
1977	Mar. 31	898.59	33.63
	May 16	898.67	33.59
	June 2	898.71	33.59
	Oct. 25	898.54	33.70
1978	Aug. 14	898.54	33.71
	Oct. 17	898.59	33.65

Table 62. Relationship between daily Gull Lake elevation (m) and observation well water level recorded on the next day (m), 1965 to 1978.

YEAR	GULL LAKE DATE	GULL LAKE LEVEL (m)	OBSERVATION WELL DEPTH (m)
1965	Aug. 18	899.41	32.81
	Sept. 28	899.36	32.86
1967	Nov. 9	898.93	33.58
1968	May 6	899.00	33.62
	Oct. 1	898.84	33.76
1969	Oct. 28	898.72	33.74
1970	May 28	898.81	33.67
	Oct. 16	898.65	33.63
1971	Mar. 25	898.77	33.64
	May 17	898.88	33.67
	Oct. 16	898.69	33.74
1972	Mar. 22	898.74	33.66
	June 27	898.90	33.63
	Nov. 2	898.72	33.70
1973	May 17	898.87	33.71
	Nov. 5	898.73	33.73
1974	Nov. 7	898.89	33.60
1975	Mar. 5	898.89	33.70
	May 16	899.07	33.60
	Oct. 28	898.76	33.67
1976	May 18	898.84	33.63
	Oct. 27	898.55	33.64
1977	Mar. 31	898.59	33.65
	May 16	898.67	33.60
	June 2	898.71	33.59
	Oct. 25	898.54	33.70
1978	Aug. 14	898.54	33.70
	Oct. 17	898.59	33.64

Table 63. Relationship between daily Gull Lake elevation (m) and observation well water level recorded on the previous day (m), 1965 to 1978.

YEAR	GULL LAKE DATE	GULL LAKE LEVEL (m)	OBSERVATION WELL DEPTH (m)
1965	Aug. 18	899.41	32.80
	Sept. 28	899.36	32.87
1967	Nov. 9	898.93	33.54
1968	May 6	899.00	33.61
	Oct. 1	898.84	33.72
1969	Oct. 28	898.72	33.73
1970	May 28	898.81	33.67
	Oct. 16	898.65	33.65
1971	Mar. 25	898.77	33.70
	May 17	898.88	33.68
	Oct. 6	898.69	33.70
1972	Mar. 22	898.74	33.70
	June 27	898.90	33.62
	Nov. 2	898.72	33.71
1973	May 17	898.87	33.71
	Nov. 5	898.73	33.76
1974	Nov. 7	898.89	33.57
1975	Mar. 5	898.89	33.70
	May 16	899.07	33.62
	Oct. 28	898.76	33.70
1976	May 18	898.84	33.59
	Oct. 27	898.55	33.64
1977	Mar. 31	898.59	33.63
	May 16	898.67	33.60
	June 2	898.71	33.60
	Oct. 25	898.54	33.68
1978	Aug. 14	898.54	33.73
	Oct. 17	898.59	33.64

Table 64. Relationship between monthly Gull Lake elevation (m) and mean monthly observation well water level (m), 1965 to 1978.

YEAR	GULL LAKE		OBSERVATION WELL
	DATE	LEVEL (m)	DEPTH (m)
1965	Aug.	899.41	32.79
	Sept.	899.36	32.84
	Nov.	899.32	32.90
1966	Oct.	899.24	33.28
1967	Nov.	898.93	33.56
1968	May	899.00	33.64
	Oct.	898.84	33.70
1969	May	898.89	33.68
	Oct.	898.72	33.77
1970	May	898.81	33.66
	Oct.	898.65	33.61
1971	Mar.	898.77	33.67
	May	898.88	33.67
	Oct.	898.69	33.70
1972	Mar.	898.74	33.69
	June	898.90	33.64
	Nov.	898.72	33.69
1973	May	898.87	33.70
	Nov.	898.73	33.70
1964	Nov.	898.89	33.62
1975	Mar.	898.89	33.67
	May	899.07	33.63
	Oct.	898.76	33.68
1976	May	898.84	33.62
	Oct.	898.55	33.65
1977	Mar.	898.59	33.61
	May	898.67	33.59
	June	898.71	33.64
	Oct.	898.54	33.68
1968	Aug.	898.54	33.70
	Oct.	898.59	33.64